**Appendix A**

**Historical Foundations: Sugar Plantations, Early Surface Water Systems, and Ka Loko**

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Appendix A

**Historical Foundation**
Historical Foundations: Sugar Plantations, Early Surface Water Systems, and Ka Loko

A primary focus of the investigation is to identify those facts and circumstances that may have contributed to the breach of Ka Loko Dam on March 14, 2007. This history of Ka Loko Dam, as well as the history of sugar plantation surface water irrigation systems more generally, proved to be quite significant. For example, the investigation revealed that the history of the construction of Ka Loko Dam was important to the engineering analysis of the breach.

One significant goal of the investigation was to provide recommended legislation. The history of Hawai‘i’s antique dams and water systems is also important to understanding the challenges faced in maintaining those systems in a modern environment. The sugar plantations devoted significant resources to the maintenance of those water systems. Today, they are still important to Hawai‘i, but the economic engine that maintained them no longer exists. Understanding the resources that have been required to maintain them in the past can help in understanding what must be done to maintain them for the future.

1 Introduction

Hawai‘i’s dams need to be considered within the larger context of the water development and delivery systems of the Islands’ plantations as they are integrated and interdependent. This Appendix briefly reviews the development of Hawai‘i’s surface water infrastructure during the sugar industry era. Many of the Islands’ contemporary dams and watersheds\(^1\) are closely related to the development of Hawai‘i’s sugar

\(^1\) A watershed is the “geographic area of land from which all runoff drains into a single waterway.”
industry’s water systems. This Appendix then examines the construction, expansion, and historical performance of Ka Loko² Reservoir, and its place within the water distribution system of Kilauea Sugar Plantation on Kaua‘i.

The majority of the sugar plantation water systems were built between 1890 and 1920, including the Ka Loko portion of the Kilauea Plantation water system which dates from 1890-1912. These systems were durable. Even today, a majority of Hawai‘i’s contemporary surface water infrastructure dates back to the sugar era when plantations developed the large irrigation structures.³ Our diversified agricultural industry remains dependent on these systems. As the Department of Land and Natural Resources (“DLNR”) reports in 2006:

Historically, the majority of dams in Hawai‘i were devoted to support the sugar cane industry. Although many of the larger plantation companies have since folded, there are still many smaller farmers that utilize the water from these old reservoirs.⁴

The primary purpose of these water systems was to provide irrigation to cane fields. Reservoir water was also used for transportation of cane from the cane fields to mills, cleaning and processing sugar, supplying hydroelectric power, as well as other plantation needs and domestic use. The plantation systems are still the backbone today of the water delivery systems in the islands. With some exceptions, Hawai‘i’s reservoirs are

² Historical and contemporary references to both Ka Loko Dam and Reservoir and Kilauea Sugar Plantation differ in spelling and word unit division used. This changes depending on the year the reference is written and the source used. Early maps and Kilauea Sugar Plantation historical documents refer to the dam and reservoir as “Koloko”. Other references to the dam/reservoir include: Ko Loko, Kaloko and Ka Loko. References to the plantation include: “Kilauea Plantation”, “Kilauea Sugar Company”, “Kilauea Sugar Plantation”, “Kilauea Sugar Plantation Co.” and “Kilauea Sugar Plantation Company Ltd.,” depending on the stage of development and ownership of the plantation.
³ For example, a significant portion of Maui’s water supply structures used today were originally constructed by plantations for the purpose of irrigating sugar cane.
⁴ Department of Land and Natural Resources: Engineering Division. Hawai‘i Flood Management News, 1 (June, 2006).
small, as the geology, soil and water cycles do not lend themselves to large water storage areas.\(^5\)

2 Background

2.1 Changes to the Traditional Hawaiian Practices as Related to Water

Prior to Captain James Cook’s arrival to the Islands in 1778, Hawaiians had an unwritten strict code of regulation regarding the distribution of water for irrigation.\(^6\) All land and water was disposed of by the King but ordinary disposition of the water (and land) was done by the chiefs to the common people, who were occupants and farmers. The remaining water was diverted back to natural streams. The purpose was to enable enough water for all persons cultivating the land, while at the same time conserving the health of the streams. For example, some of the traditions governing the use of dams and ditches\(^7\) to alter stream flow included the following:

[In] some ditches not all of the water was used but after irrigating a few patches the ditch returned the remainder of the water to the stream.....dams were always composed of loose stones and clods of earth and grass and were not made tight but so as to permit some of the water percolating. No dam was permitted to divert more than one-half of the water flowing in the stream at the point of diversion and the quantity taken was generally less. Lower holders [people farming on lower grounds] were likewise entitled to water and their rights were respected.....prior to the Mahele, under the ancient Hawaiian systems.....disputes concerning water were extremely rare. The aim of the konohikis and of all others in authority was to secure equal rights to all and to avoid quarrels.\(^8\)

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\(^7\) “The water development systems went by the title of “ditches.” [This is] misleading because they were not all ditches- many were mostly flumes, siphons, and tunnels- and humble because their size and scale were often quite large….Very few watersheds escaped the winding, burrowing network of ditches.” Carol Wilcox, Sugar Water: Hawai’i’s Plantation Ditches, 16 (1996).
Hawaiian society did not have the concept of private acquisition of land and water.

The fundamental conception of property and law was based upon water rights rather than land use and possession. Actually there was no conception of \textit{ownership} of water and land, but only of \textit{use} of water and land.\footnote{Lawrence H. Miike, Water and the Law in Hawai‘i, 49 (2004).}

The Hawaiian water source delivery systems and organization was well designed and continued supplying the expanding economy for a century following Cook’s arrival. However, newcomers to Hawai‘i increased the cultivated land area and the demand on the islands’ water sources. At first western sugar manufacturers leased land or relied on cane that Hawaiian’s produced on small plots. Eventually, water consumption, especially the large amounts of water needed for growing sugar cane, exceeded the supply from the available Hawaiian distribution network.\footnote{http://www.wrrc.Hawaii.edu/publication/contributed-paper/CPabs.html}

The Hawaiian practice of sharing natural resources such as water and land, or holding them in common trust for the use of the whole population, was foreign to the increasing number of westerners arriving in the Islands. This social change regarding land use, rights and concepts of ownership continued when in1846, King Kamehameha III formed a land commission (by Act of April 27, 1846). This lead to the Great Mahele in which land titles were given out to royalty, ali‘i and konohikis, and the government. The developing practice of “ownership” widened to a larger range of potential private land owners in 1850, with the Kuleana Act (sometimes referred to as the second Great Mahele). The Kuleana Act enabled common people, maka‘āina or hoa ‘āina, to also become owners of the land.

Foreign investor’s sought to cultivate additional land by transporting water away from its natural steam beds. This large-scale water infrastructure development irrigating

\cite{lawrence_miike_water_law_hawaiian_society}
dry areas of land, expanded the cane fields and increased the scale of production. With changing laws and legislation there were increased development opportunities as well as increased confusion regarding land and water use:

With assured ownership of distinct pieces of land in individuals and particularly with the advent of foreigners accustomed to more definite delimitation of rights of property, possessed of more advanced knowledge in the art of cultivation and imbued with a keener desire for material prosperity, and, as to some localities, with a decreased rainfall, came more frequent and more intense misunderstandings and differences concerning the ownership of water.

The Kuleana Act opened the way for the expansion of the sugar industry because it enabled foreign-born sugar planters to buy land. This trend of change continued in 1876:

[The Reciprocity Treaty] was predicated on full government support of the fledgling sugar industry, including its efforts to develop water. Without that support, which included allowing the sugar planters to transport water out of the watershed, investors would not have been attracted to Hawai‘i.

By 1910, western developers had constructed so many collection works and transmission systems, that virtually every major surface water resource was seized for plantation agriculture. Without help from government entities, plantations engineered and maintained large water structures with private capital.

Expansion of plantation lands altered other social conditions in the Islands. By 1930, fifty per cent of all the population of the Territory outside of Honolulu and Hilo

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11 Personal Communication: Carol MacLennan (December 13, 2006).
14 Carol Wilcox, Sugar Water: Hawai‘i’s Plantation Ditches, 16 (1996).
lived on sugar plantations. At this time, Hawaiian Sugar Planters Association statistics showed that of the 154,270 gainfully employed persons in the Territory of Hawai‘i, forty per cent were employed on sugar plantations.

### 2.2 Western Influence and the Sugar Industry

Hawaiians originally brought sugarcane to these islands. They constructed sophisticated irrigation systems using basic tools to irrigate taro as a paddy crop. They planted sugar cane, banana and other crops on the banks of the taro lo‘i. While the systems were intricate, they did not include tunneling and they did not move water out of the watershed. The stream reservoirs were highly valued, and in no case of record were streams dewatered.

Hawaiians chewed on the cane but did not process it into sugar. In 1802, Chinese immigrants on Lānaʻi demonstrated Chinese technology of producing sugar crystals that could be used as an exportable commodity. Koloa Sugar Company on Kauaʻi was established in the 1830’s and became the first successful plantation in Hawaiʻi.

A complex combination of world events around this time led sugar to become the industry of choice for investors and entrepreneurs: changes in local land use and ownership, advances in processing cane into sugar, demise of earlier economic engines, available fertile land, year round sun, abundant water, benefit of emerging technology, and, critically, the monarchy’s willingness to lease water rights. In 1876, the first license

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17 Statement on Behalf of Thirty-nine Plantations to the United States Department of Agriculture Agricultural Adjustment Administration, Re: Marketing Agreement for Sugar Produced in the Territory of Hawai‘i, 64 (April 24, 1935).
18 Id.
to take water from streams was granted. “By statute these grants [were] in the form of a license with specific time and payment terms.”

In 1850, the Hawaiian Kingdom and the United States committed to peaceful political and economic relations through the Hawaiian-American Treaty of Friendship, Commerce, and Navigation of 1849. By the 1880’s sugar was a lucrative commercial crop and developing plantations were becoming “the bone and sinew of the Hawaiian sugar industry.” There were ninety sugar planters, plantations and mills in Hawai‘i in 1884. When the United States signed the Reciprocity Treaty with the Kingdom of Hawai‘i, the Treaty enabled sugar to be imported into the United States duty free in exchange for certain rights at Pearl Harbor. This meant even more significant profits for the sugar industry, and plantations expanded “at an exponential rate.”

3 Development of Hawai‘i’s Sugar Cane Infrastructure

3.1 Thirsty Cane

In order to establish a successful sugar business, it was critical to have a reliable source of water. In the 1880’s planters became concerned about the drought caused by deforestation throughout the Islands. This spurred extensive development of water for irrigation. Sugarcane requires a plentiful and consistent supply of water throughout its growing-cycle. The tropical climate in Hawai‘i enables cane to be cultivated for the full

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20 Before 1915 the government had granted a water license to Kilauea Sugar Company (for Moloa‘a). Carol Wilcox, Sugar Water: Hawai‘i’s Plantation Ditches, 18 (1996).
26 Personal Communication: Carol MacLennan (December 13, 2006).
twenty-four months until its peak sugar content. The irrigation system needed to supply enormous quantities of water over long distances to numerous cane fields throughout the year. Additional water was also used for fluming cane to the mill, and for cleaning and processing.

The sugar plantations also established worker housing called “camps,” and eventually company stores. These evolved into communities with town squares, churches, and hospitals. These camps and town facilities needed a water and energy supply. Many plantations developed hydroelectric power for their mills and supporting communities.

### 3.2 Collaboration among Plantations

Sugar plantations became the center of Hawai‘i’s economy. Cooperative networks of small sugar farmers, plantation managers, and plantation start-up owners played a key role in the development of sugar production methods. Sugar planters in the Islands encountered similar engineering problems as they sought to irrigate and cultivate Hawai‘i’s rugged terrain and lava-based soils. They struggled with water and labor shortages and had difficulty establishing markets because of the Islands’ isolated location, 2300 miles from the mainland.

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28 At harvest, gate tenders at the reservoirs would open the sluice gates and cane could be flumed downstream to mills. William H. Dorrance, Sugar Islands: The 165-year Story of Sugar in Hawai‘i, 89, (2000).
In 1882, sugar planters in the Kingdom of Hawai‘i organized the Planters’ Labor and Supply Company, which primarily focused on importing labor for the plantations. This later became the Hawaiian Sugar Planters’ Association (“HSPA”) in 1895, aiding planters in research and labor relations. This scientific/engineering organization promoted sugar production in the islands and advanced the mutual benefits of its members.

One reason for the financial success of Hawai‘i’s sugar industry was the application of both engineering and science, and the cooperative sharing that HSPA fostered. Based in Honolulu, HSPA had regular meetings on the different islands enabling further discussion and collaboration among plantations. HSPA conducted research on soil chemistry and recommended irrigation methods that would be appropriate to Hawai‘i’s terrain. Growers shared information about irrigation structures, crop development, plantation management and marketing. These collaborative efforts and sharing of technology resulted in commonality in plantation structures and practices.

HSPA established a research station that enabled Hawai‘i’s sugar industry to be the world leader in sugar technology, research and science. By 1929, HSPA had 75 scientists and investigators in different departments, including: Agriculture, Entomology, Forestry, Sugar Technology, Pathology and Chemistry. HSPA’s expenditures for the Experiment Station averaged $469,000.00 per year from 1930 to 1934. Eventually

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33 This organization still exists today as Hawai‘i Agriculture Research Center (HARC), and conducts research on a broad diversity of crops. http://www.Hawaiiag.org/harc/HARCHS11.HTM.
HSPA determined all different aspects of the industry, setting the quality control measures for the Sugar Industry\(^{37}\) and deciding wage maximums for field workers.\(^{38}\) HSPA evolved into one of the most progressive global think tanks in agricultural history.\(^{39}\) Hawai‘i remains a world leader in agro-biotechnological research.\(^{40}\)

### 3.3 Building Technology

#### 3.3.1 Precious Resource: Hawai‘i’s Terrain and Water Management

Because of the monumental amounts of water needed to grow cane, farmers could not just depend on natural water sources. The value of water during the plantation era, perhaps, easy to underestimate today. A 1941 report done by the Division of Hydrography of Territory of Hawai‘i for the Senate and House of Representatives Legislature of the Territory of Hawai‘i elucidates the value that water had in some parts of the Islands during the sugar plantation era. The report describes a survey of water resources in the district covering the “Kalaheo, Lawai and Omao Homesteads” of Kaua‘i.\(^{41}\) An engineer reviewed different means of irrigating a dry area of the island for commercial farming and encountered the challenge of transporting water from an available source in a way that would still enable a profit. One possibility investigated was the joint use of Alexander Reservoir. However, because rental of water from Alexander would likely have to be repaid in millions of gallons of water rather than in a monetary form, this rental would not be profitable. The estimated rental agreement details the

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\(37\) Posted information about HSPA in Sugar Plantation exhibit at Kaua‘i Historical Museum, October 25, 2006.

\(38\) In 1901, HSPA established a maximum monthly wage ranging from $18 to $24 per month depending on plantation locale. http://www.findarticles.com/p/articles/mi_qa3933/is_200005/ai_n8892465/pg_5.


\(41\) “Report of the Division of Hydrography of the Territory of Hawai‘i on the Survey of the Water Resources of the District Covering the Kalaheo, Lawai and Omao Homesteads, Kauai” (1941).
calculated interest in water (in terms of millions of gallons a day of water, rather than monetary interest) that would be required to rent from McBryde Sugar Company. Finally it is determined that developing this land was not possible; “with water so dear to begin with . . . . the only proposals investigated that could furnish sufficient water would appear to be too expensive to be practical.”

The sugar business also required substantial amounts of capital and ingenuity for large-scale water development. After locating a watershed, plantations needed to create an irrigation system that workers could monitor and control for consistent irrigation use.

However, surface water in Hawai‘i is unreliable. The flow rates in Island streams are flashy, they tend to rise and fall rapidly with rainfall. This can happen over a period of a few hours. Frequently, storm flows will be hundreds or thousands of times greater than median stream flow rates. Because of the steep grade of Hawai‘i’s mountain cliffs, runoff water from rain quickly makes its way down the slopes through low-lying arable land to the ocean.

Plantation surveyors and engineers investigated watershed’s supply sources, yearly weather cycles and land contours. This involved extensive research. In 1889, B.F. Dillingham invited James D. Schuyler and G. F. Allardt, two well-known civil engineers experienced in hydraulic works, to survey the “Honouliuli and Kahuku Ranchos”. In their report to Dillingham, they expressed their shock that they could not find regular systematic water irrigation studies:

In making these examinations we have been impressed with the fact that there is great need for a systematic study of the water supply available for

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44 Carol Wilcox, Sugar Water: Hawai‘i’s Plantation Ditches, 7 (1996).
irrigation throughout the islands generally by experienced hydraulic engineers—and the collection and publication of just such data as we have been groping for very much in the dark.....Where water is so valuable as it is here, it would seem to be quite worth while to take an account of stock occasionally, to ascertain what you have, what is done with it and what further good it can be made to accomplish.45

In order to conduct their study, Schuyler and Allardt looked at the best irrigation records they could find, located at Hawaiian Commercial Company Plantation on Maui. It is impressive to note the sophisticated accuracy some early plantations had to monitor rain run-off. Despite the expressed general lack of information about water availability in the islands, in 1888 this plantation had a detailed recording system. Schuyler and Allardt describe the variability of the water source and precision of plantation recording in their report:

The plantation is irrigated from the Haiku ditch, gathering its supply from some twenty small streams to the eastward of the plantation, and by the Waiheee ditch, deriving its waters from the Waiheee creek, some miles to the west. Each ditch delivers to the plantation a maximum supply of about 65 cubic feet per second; but this maximum is not often reached, and the ditches appear to be subject to great fluctuation in supply. Several small storage reservoirs along the route serve to equalize the fluctuating discharge to some extent. Measuring weirs are placed on each in such position that the quantity of water actually delivered to the fields is recorded with great exactness by automatic registering apparatus. The volume of water put upon every field is thus known, and the date and quantity of each watering. The records further show in every detail all the results obtained from each field, including the average yield of each in sugar per acre, as well as per unit of water applied.46

Monitoring and managing water sources in accordance with the weather enabled plantations to make the most of this precious resource. Surface water systems had to be

46 Id. at 4.
constructed and managed so that they would contain water following storms, as well as, during the dry season months.

The irrigation ditches often did not follow the natural land contours. Plantations’ complex water projects diverted substantial amounts of water. This included emptying or crossing natural streams (with flumes) and piercing hills and mountains to reach cane fields.\textsuperscript{47} Because water was not flowing in accord with natural streambeds, additional maintenance and management of ditches, flumes, siphons and other works were required. During storms and flood waters when there were significant changes in the stream levels, the ditch laborers were especially needed.\textsuperscript{48}

### 3.3.2 Hawai‘i’s Plantation Surface Water Irrigation Engineering

The early plantation dams and irrigation systems in Hawai‘i were constructed at a time when people were just beginning to understand the relationship between soil mechanics and engineering. The field and basic standards of geotechnical engineering were not yet established. Plantation engineers and HSPA staff were starting to examine and classify dam bank reserves. Plantations sent soil samples to the HSPA chemistry department (in addition to the plantations’ own departments and experimental stations) to investigate the soil’s chemical make-up.

For example, Mr. Joel B. Cox of McBryde Sugar Company on Kaua‘i, educated at Stanford as a civil engineer, was the designer and chief engineer in the construction of Alexander Dam.

\textsuperscript{47} Carol Wilcox, Sugar Water: Hawai‘i’s Plantation Ditches, 5-6, 98-106 (1996).
\textsuperscript{48} Kilauea Sugar Company Irrigation System, Table D-2, records show the present conditions of ditches, iron flumes, flumes, siphons, v-flumes and their present condition, “inoperable”, “poor” or “good” (1960’s) Kilauea Sugar Company Records, Kaua‘i Historical Society.
[In 1929, Cox requested HSPA to] amplify certain fundamental engineering and chemical concepts which he felt were critically applicable and, in some cases, vital to this particular structure. The control program began in a very modest manner in October, 1928, by a standardization and expansion of soil colloid tests which were of value in the classification of core and beach material then being sluiced to a pilot dam. Variability in specific gravity, ratio of fine to coarse aggregates in the flumed material, solubility affects of the mountain waters on the soil constituents and settling characteristics of the water suspended core materials were the first problems encountered.  

Therefore, a few early dam builders in the Territory of Hawai‘i were beginning to investigate how soil quality determined soil stability under pressure.

The HSPA chemistry researchers found that the “borrow pit” next to the Alexander building site had a high acid reaction and silty character.

[They discovered the soil] could apparently be given the properties of dense or fat clays by a very simple chemical treatment...[This conversion resulted in increasing]...the ability of the treated material to resist the passage of water by upwards of 300 to 1000 per cent.  

This newly combined chemical and engineering research and the development of HSPA’s control program meant that soil consolidation, permeability, solubility, settling characteristics, plasticity, cracking qualities on surface drying....and other physical properties were beginning to be understood. This helped determine the methods used in constructing and maintaining the reservoirs, dams, tunnels, irrigation ditches.

The soil consistency also determined what was necessary for the cultivation of sugar cane. For example, in 1914 Peekeo Sugar Company’s acidic lands required liming for neutralization. C. Brewer & Company, Ltd. used a unique method to achieve this.

[O]ver 20,000 tons of O‘ahu’s Wai‘anae Coast coral sands were taken by the O.R.&L. railroad to the Honolulu docks, then via the Inter-Island Steam

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50 Id. at 2.
51 Id. at 0, 2.
Navigation Company to the Hilo docks, and onward with the Hawai‘i Consolidated Railway Company to Pepe‘ekeo. There the sand was bagged and hauled into the fields by mules to be spread. This remarkable effort turned the acidic soil into a hospitable host for sugarcane and the machinery used to cultivate it.52

As early sugar planters developed knowledge about Hawai‘i’s lava-based earth, they found techniques to alter the soil’s chemistry for the better production of cane.

3.3.3 Earthen Dams and the Hydraulic Fill Method

Earthen dams account for more than 95% of dams in Hawai‘i’s Dam Safety Program inventory.53 Following the October 15, 2006 earthquakes, the Earthquake Engineering Research Institute described damage to several of these dams:

Most dams in Hawai‘i are old earthen berm reservoirs built during the plantation era for irrigation purposes. [The October earthquake damaged ditches and] at least two dams cracked along their crests, while at least two others showed clear evidence of incipient slope failure on their embankments.54

One safety issue with earthen dams is that they are susceptible to liquefaction during an earthquake. A historical example of dam liquefaction damage is what happened to Sheffield Dam following the Santa Barbara Earthquake in 1925.

A 300 ft section (of the 720 feet long dam) moved as much as 100 ft downstream. The dam consisted mainly of silty sands and sandy silts excavated from the reservoir and compacted by routing construction equipment over the fill….the disturbance needed to trigger flow liquefaction can, in some instances, be very small.55

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53 Department of Land and Natural Resources: Engineering Division, Hawai‘i Flood Management News, 1 (June 2006).
Both in California and Hawai‘i at the end of the 1800’s a number of dams were being constructed and many of these were made out of earth, or a combination of earth and rock.\textsuperscript{56}

At this time, a new process of building earthen dams, the hydraulic fill method, was considered “a novel manner of building dams of earth and gravel.”\textsuperscript{57} The “hydraulic fill” was the embankment that was created as earth was sluiced, or transported in suspension in water, to the embankment. “It consists in excavating, transporting, and depositing the material required by the erosive action of water, which is obtained either under pressure from a jet or by gravity from a flume.”\textsuperscript{58} The low embankments were built up as the fill progressed defining the dams’ edges. The separation of the course and fine material through the process of sedimentation produced a watertight core. Hydraulic fill dams rely on their weight to hold back the water.\textsuperscript{59}

The hydraulic process was used on O‘ahu to construct a dam for Waialua Sugar Plantation. In 1903, engineer James D. Schuyler, was consulted on how to construct this dam. Schuyler had a general theory about design and construction using hydraulic-fill.

First: That the inner third of the dam should be composed of material which should consolidate into a mass impervious to water. Second: That the outer half of each of the other thirds of the dam should consist of a porous material, permitting the passage of water, and Third: That the inner halves of the outer thirds of the dam should be a mixture of coarse and fine material, which should act as a filter to retain the fine particles of the inner third, while allowing water to percolate slowly.\textsuperscript{60}

\textsuperscript{56} \url{http://cee.engr.ucdavis.edu/faculty/lund/dams/Dam_History_Page/History.htm}.  
\textsuperscript{57} Edward Wegmann, The Design and Construction of Dams: Including Masonry, Earth, Rock-fill, Timber, and Steel Structures also the Principal Types of Movable Dams, 248 (1908).  
\textsuperscript{58} Id.  
\textsuperscript{59} If interested, please see embankment dams, subtopics: earthen dams and hydraulic fill at: \url{http://www.answers.com/topic/dam}.  
\textsuperscript{60} For further information about hydraulic dam construction at the turn of the century, please see the descriptions of Schuyler’s dam engineering in: Edward Wegmann, The Design and Construction of Dams: Including Masonry, Earth, Rock-fill, Timber, and Steel Structures also the Principal Types of Movable Dams (1908).
Schuyler recommended that Waialua’s dam be a combination of rock-fill and earth-fill and provided specifications on the dimensions and process of building.

[The dam should have] an extreme height of 98 feet and a crest width of 25 feet, 10 feet above the level of the spillway. A wooden core-wall was built in the rock-fill with its bottom embedded in a concrete wall, and the earth was to be sluiced into position against the core-wall, so as to have a slope of 4 to 1 on the water side. 61

A different engineer from California built the dam and reservoir using these recommendations.

The following describes the dimensions of Waialua Sugar Plantation’s dam, later known as Lake Wilson, 62 and details concerning the dam’s construction between 1904 and 1906:

The dam has a length on top of 460 feet, a top-width of 25 feet, and a width of 580 feet at the base. The rock-fill is 11.5 feet wide at the top and 80 feet at the base. It contains 26,000 cubic yards of loose rock, a considerable portion of which was laid by hand as a dry wall. The outer slope of the rock-fill is 3/4 to 1, and the inner side is vertical. The wooden core-wall was built in the rock-fill, 2 feet down-stream from its vertical face. It consists of double 2-inch redwood plank, laid horizontally, with a double layer of burlap dipped in hot asphaltum between the two layers of plank, and spiked to 3”x6” uprights, placed 2 feet apart, centre to centre. The bottom of the core-wall was embedded in a concrete wall built in a trench, which had a maximum depth of 38 feet below the surface and extended laterally into the hillsides from 14 to 28 feet. The trench was made 5 feet wide at the bottom, and was filled with concrete to a level slightly above the natural surface. The rock (basaltic boulders) was brought in cars to the site of the dam and dumped from a high trestle.

The water required for making the hydraulic fill was delivered by pipes from an upper ditch to a point 2,000 feet distant from, and 500 feet higher than, the dam. Ground-sluicing was resorted to, as the available heat was not sufficient for excavating and disintegrating the material. Between the point where the water was delivered and the dam there was a large quality of earth

of great depth that was considered suitable for making the hydraulic fill. For a depth of 2 or 3 feet it consisted of reddish-brown soil, under which there was a bright-red tufa [porous limestone] for a depth of 20 to 50 feet, and then yellow tufa for 50 to 100 feet more. This tufa resisted the erosive action of the water in a remarkable manner. It had no tendency to slide, and would stand vertically in trenches for a long time. It was found to be very difficult to sluice the tufa, as it contained no sand or grit to do the cutting and would settle in the pond very rapidly. The method resorted to for sluicing this material was to dig a ditch, about 4 feet deep at its upper end and 12 to 16 feet deep at the dam. Its length was about 1,300 feet. The earth on either side of this ditch, for a width of 12 feet, was loosened by a steam-plow and dumped by scrapers into the running water in the ditch, which had sufficient velocity to carry the earth to the dam. This was found to be the only practical way of handling the tufa, as the water had no effect when turned upon the plowed ground, and ran over it perfectly clear.

The process described above was continued until the ditch grade was reached when a new strip would be plowed and the ditch would be shifted over to the bluff-bank on either side of its original position. The total cost of placing the earth in the dam, by the method described above, amounted to 11 cents per cubic yard. The hydraulic fill has a volume of 141,000 cubic yards. It is reported to be very hard and perfectly water-tight. The reservoir formed by the dam stores 2,500,000,000 gallons.63

This seven mile-long reservoir is still Hawai‘i’s highest earthen dam today, at 136 feet.64

The hydraulic technique used the local resources of earth and rock, thereby making it the most economic process of constructing dams.

In 1927, the hydraulic fill method was also used on Kaua‘i for Alexander Dam. The dam was constructed to capture water to irrigate the fields of McBryde Sugar Company, Ltd. At the end of construction, March 25, 1930, the dam failed and collapsed causing the death of 6 people.

Around this time, Dr. Karl Terzaghi, who had a background in engineering and soil mechanics, was demonstrating the relationship between the fields of engineering and

64 Carol Wilcox, Sugar Water: Hawai‘i’s Plantation Ditches, 109 (1996).
soil mechanics. In 1925, he had published a seminal paper with new techniques for investigating, testing and analyzing soil data that later defined the field of geotechnical engineering. Joel B. Cox (who later became President and Chair of the Engineering Association of Hawaii’i) had initiated the construction of Alexander Dam using Terzaghi’s principles of soil mechanics, and now sought his advice. Through correspondence Terzaghi guided Cox in reconstructing the dam, which was completed in 1931. Alexander on Kaua’i, at 119 feet high, is one of the highest hydraulic fill dams in the western United States.

Today, the hydraulic fill method of earthen dam construction is considered outdated because of potential safety hazards. Contemporary zoned-earth embankments use a filter and drain to separate and remove seep water to preserve the integrity of the dam. In Hawai’i, especially following our recent earthquakes, we need to pay special attention to dams that were constructed with the hydraulic fill method, as well as other kinds of earthen embankment dams. The Islands’ early plantation dams were constructed without seismic detailing.

68 “Earth dams, also called earthen, rolled earth and earth-fill dams, are constructed of well compacted earth.…A zoned-earth dam has distinct parts or zones of dissimilar material.” http://www.answers.com/topic/dam
69 For example, the earthen embankment dam at Nu’uanu Reservoir No. 4. James D. Schuyler, well known for his construction of dams by hydraulic fill, was a consultant engineer to the Territorial Government of Hawaii on Nu’uanu Dam, Honolulu. www.asce.org/files/pdf/history/sec.5.pdf. Between the proposal of the reservoir in 1890 and the start of construction in 1905 there were a number of significant political events that delayed work on the dam. Wiliki o Hawaii: Engineer of Hawaii, Vol. 42 No. 7, 10 (September, 2006). On July 29, 1905 the construction commenced and the work involved “sluicing operations at the dam…[because] sluicing was the preferred method of construction as it cost 15 cents “a square yard” vs. 56 cents “by other methods.” Wiliki o Hawaii: Engineer of Hawaii, Vol. 42 No. 9, 10 (November, 2006). Schuyler was brought back to Hawaii’i “in 1907 to “rescue” and redesign the Nu'uanu Dam.” http://www.ascehawaii.org/heritage.html.
3.4 Construction, Costs and Sugar Factors

During the sugar industry’s development, approximately 1880 to 1920, significant investment was made in the plantations, including most of the major water collection systems.70 From 1920 to approximately 1950, sugar businesses were profiting, collection systems were expanded, and irrigation systems were refined.71

Building irrigation structures cost hundreds of thousands and sometimes millions of dollars.72 The production of sugar was “made possible by great irrigation systems, representing millions in capital, conceived and built by the plantations.”73 While construction and maintenance of these systems was what made the plantation’s sugar production possible,74 the on-going maintenance, supplies and labor needed to keep them running was costly. Plantations usually started as independent enterprises and later were forced into bankruptcy, merged and owned or controlled by one of Honolulu’s conglomerates. The “Big Five” and smaller two factors were;

Alexander & Baldwin (now A & B-Hawai‘i, Inc.); American Factors, Ltd. (today’s Amfac/JMB-Hawai‘i, Inc.); C. Brewer & Company, Ltd.; Castle & Cooke, Ltd. (today’s Dole Food Company); and Theo H. Davies & Co., Ltd. (acquired by Jardine Matheson & Co. in 1973, and no longer a sugar factor). They were joined by the smaller F.A. Schaefer & Co., Ltd., representing wholly owned Honokaa Sugar Company, and Bishop Trust Company, representing Gay & Robinson’s plantation on Kaua‘i.75

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70 “By 1920, most large plantations had put at least $500,000 into water development, some much more.” Carol Wilcox, Sugar Water: Hawai‘i’s Plantation Ditches, 17 (1996).
72 For example, O‘ahu Sugar Company’s initial cost for the construction of Waiahole Ditch (around 1913) was $2.3 million. The ditch consisted mostly of tunnels dug into and eventually through the hard rock of the Koolau Range. In West Kaua‘i in the 1920’s the construction of one ditch, Kokee Ditch, cost Kekaha Sugar Company more than $500,000. Carol Wilcox, Sugar Water: Hawai‘i’s Plantation Ditches, 96 & 98 (1996).
73 Statement on Behalf of Thirty-nine Plantations to the United States Department of Agriculture Agricultural Adjustment Administration, Re: Marketing Agreement for Sugar Produced in the Territory of Hawai‘i, 23 (April 24, 1935).
74 Id. at 23-24.
75 William H. Dorrance, Sugar Islands: The 165-year Story of Sugar in Hawai‘i, 7 (2000).
These companies loaned money for the start-up costs of construction or funded subsequent expenses. The Big Five controlled over 90 per cent of the Islands’ sugar production by 1930. By 1935, thirty-seven plantations produced 98 per cent of the sugar of the Territory and all of them were members of the cooperative HSPA.

By the 1950’s the sugar industry was increasingly challenged and irrigation infrastructures were aging. One way plantations reduced their expenses was by cutting the labor and material repairs and maintenance on the water systems.

4 Kilauea Sugar Plantation

4.1 Kilauea Sugar Plantation Ownership and Development

In 1863, Charles Titcomb purchased Kilauea land to raise cattle. Edwin P. Adams and Captain John Ross, both from Honolulu, purchased three thousand acres and six thousand head of cattle from Titcomb in 1877. Adams and Ross gradually converted the ranch lands into sugar cane fields. Adams eventually bought out Ross. Sugar operations had begun in 1877 and Kilauea Sugar Plantation Co. was incorporated with the first harvest three years later.

In 1899, Adolph and J.D. Spreckels of San Francisco (sons of Claus Spreckels) and W.G. Irwin purchased Kilauea plantation and incorporated it in California as the Kilauea Sugar Plantation Company. Irwin, residing in Honolulu, served as agent and held

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76 “These agencies acted as bankers for the plantations they represented. They advanced operating funds secured by future sugar sales and financed the plantations by buying primary or secondary stock issues.” William H. Dorrance, Sugar Islands: The 165-year Story of Sugar in Hawai‘i, 7 (2000).
77 http://www.findarticles.com/p/articles/mi_qa3933/is_200005/ai_n8892465/pg_5
approximately one-third of the stock. When Irwin moved to San Francisco, he selected Walter M. Giffard to manage the Honolulu office of the WG Irwin agency. Then in 1909, C. Brewer (founded in 1826) bought Irwin’s agency, becoming the business agent for the plantation. The Spreckels brothers held stock in the plantation until 1948 when they sold their interest to C. Brewer, who became the majority owner.  

At that time, C. Brewer owned many plantations; Kilauea Sugar Plantation (KSP), with its marginal production, was never a priority investment although C. Brewer supported KSP for a long time.

Kilauea Sugar Plantation was a member of the HSPA and benefited from its cooperative technological and agricultural research. In fact, one of KSP’s managers, David P. Larsen, “was formerly in charge of the field experiments of the HSPA experiment station and transferred to practical cane growing when the directors of Kilauea made him an attractive offer.”

The plantation steadily grew in its work force, acreage, irrigation infrastructure and production. However, KSP faced several challenges. It was located on a dry and remote location on the northeast shore of the island. Other plantations on Kaua‘i were able to produce ten tons per acre, but the soil, isolation and water difficulties at KSP enabled it to only reach an average six tons per acre. KSP was also far from a major harbor, which made it difficult to ship out sugar. Because of these circumstances it always had a marginal production, one of the smallest in the islands. For most of its existence, the plantation operated at a financial loss. Managers that could make it at KSP

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82 Personal Communication. Carol MacLennan, Michigan Technological University, December 13, 2006. Professor MacLennan provided information from her research on Kilauea Plantation’s ownership history.
83 http://www.bizjournals.com/pacific/stories/206/05/15/daily79.html
85 Jared G. Smith, Plantation Sketches: A record of Hawaiian Industries as They Appeared to an Itinerant Journalist in 1923; Published in the Columns of the Advertiser, 9 (1924).
were considered qualified candidates for promotion to larger plantations in the islands.\(^\text{87}\)

However, the plantation’s challenges led it to be one of the most innovative plantations, applying new techniques and inventions.\(^\text{88}\) During the height of KSP’s sugar production, the plantation employed 400 people.\(^\text{89}\)

### 4.2 Water in Kaua‘i and Kilauea Sugar Plantation’s Water Source

Kaua‘i, was an attractive region for plantation start-ups since it, on the whole, receives more water than the other islands. Mt Waialeale, at 5,148 ft., is often quoted as the wettest place on the planet, is the source of the islands 7 major rivers.\(^\text{90}\) Mt. Waialeale and Mt. Kawaikini (5,243 ft.) proved an excellent supply of water for sugarcane irrigation. Mt. Waialeale averages rainfall of over 472 inches (39 feet or12 meters) each year.\(^\text{91}\) Because of this;

The term, “water development,” therefore, has a different meaning on Kauai than in most lands, for it simply means catching and holding tremendous floods of pure rain water. There is water there, floods of it!\(^\text{92}\)

However, a good portion of Kaua‘i’s rainfall is seasonal and 43% of the island’s water-budget is runoff from storm water that cascades down the mountains to the ocean.\(^\text{93}\)

KSP’s main water source was surface water directed through ditches and stored in reservoirs. This water source fluctuated with the seasons and heavy rain storms or

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\(^\text{87}\) William H. Dorrance, Sugar Islands: The 165-year Story of Sugar in Hawai‘i, 24 (2000).
\(^\text{88}\) “Kilauea was among the earliest to experiment with locomotives for transporting cane, with gasoline tractors to replace the steam plow, and, in 1937, with the first machines to clean cane.” Carol Wilcox, John Wehrheim and T.K. Kunichika, The Kauai Album, 128 (1981).
\(^\text{89}\) The town of Kilauea was developed entirely as an extension of the plantation community. When the plantation eventually closed it had decreased to 200 employees. Carol Wilcox, John Wehrheim and T.K. Kunichika, The Kauai Album, 127 (1981).
\(^\text{92}\) Jared G. Smith, Plantation Sketches: A record of Hawaiian Industries as They Appeared to an Itinerant Journalist in 1923; Published in the Columns of the Advertiser, 13 (1924).
\(^\text{93}\) http://hi.water.usgs.gov/pubs/abstracts/wr95-4128.html
occasional droughts. The plantation’s records document significant changes in the amount of rainfall, and the corresponding limitation, or, abundance of water.

The following section elaborates on the fluctuations in Ka Loko’s water level and the rainfall at KSP.

[On July 15, 1904,] Kaloko Reservoir had very little water in it, 4 feet 6 inches, the supply coming in by the mountain ditch was about from six to seven men’s supply for irrigation, and by July 2nd the reservoir was totally empty.\(^4\)

In contrast to this, mid-September of 1905 the water is measured at twenty-six feet for ten days.\(^5\) In 1910, Kilauea reservoirs are assessed to be in good condition;\(^6\) that year in April the dam held 30 feet of water and 27.11 feet in December.\(^7\) May of 1911, the dam held 33.3 feet of water.\(^8\) Then, even though the dam was raised and reservoir expanded in 1911-1912,\(^9\) a photograph of Ka Loko taken in 1921 shows a low water level. In the photograph, cattle are lying down and grazing on a wide portion of the reservoir that is emptied of water.\(^10\)

Years later, there is still great variation in Ka Loko’s water levels. For example, in April 18, 1955, it is 38.5 feet and July 9, 1955, it is down to 20 feet.\(^11\) That November, manager, E. Smith recorded floods that damaged part of Kilauea’s ditch system.

\(^4\) Kilauea Sugar Plantation Co., Report on the length of time taken for the water to reach fields after leaving reservoirs (1904), Kaua’i Historical Society.


\(^10\) “Koloko Reservoir, Kauai c. 1921”, (1921), Kaua’i Historical Society.

Our large irrigation supply ditches could not carry the tremendous volume of water and overflowed in many places. Our mauka ditch system was damaged due to hundreds of landslides and breaks in the banks. The cement waterhead of the Koloko Ditch was washed away and will have to be restored. Main supply ditches were silted in level at many points. The Kaliihiwai River rose to an unprecedented height,toppling two large concrete piers that supported the siphon as it crossed the river, 25’ above normal water level.\textsuperscript{102}

The next year in November 1956, the Soil Conservation Service describes another Kaua‘i downpour as the type that could be expected once in a hundred years.\textsuperscript{103} In a 48 storm, between January 24\textsuperscript{th} and 25\textsuperscript{th}, 43.5” inches of rainfall were recorded at the KSP office gauge.\textsuperscript{104}

In contrast to this, KSP’s 1959 annual report describes several distinct dry spells, with rainfall that was less than the ten year average. The drought required increased intervals of opening the reservoirs’ outlets to flood to the cane fields and reduced the reservoirs’ reserve. The same year, a hurricane broke sugar cane stalks, resulting in the loss of sugar ton per acre for the next two crop years.\textsuperscript{105} In 1964, KSP’s President reported that the rainfall was 21 per cent above the average of the previous ten years.\textsuperscript{106} In conclusion, the plantation’s records demonstrate great variation in both Ka Loko’s reservoir level and the amount of rainfall. Seasonal high and low water levels are evident, as well as occasional floods or droughts.

4.3 **Kilauea’s Water System**

A 1910, Kilauea Sugar Plantation handwritten report lists at least six Reservoirs: Kalihiwai, Stone Dam, Small Dam, Waiuli, Waiakalua and Ka Loko. The construction and completion of “Lawrence Dam” is shown in photographs taken on Kilauea Sugar Plantation around 1911. The KSP records document nine major ditches in the mid 1900’s: Princeville, Kalihiwai, Pu‘ukaele, Kaloko, Moloaa, Ross, Mill, Lawrence, and Koolau ditches.

Later, KSP is noted to have six reservoirs connected by four small ditch systems, fed by many small streams. By 1931, the 33 miles of main ditching is practically all earth-lined, and the remainder is stone-lined. The reservoirs named are: Koloko [Ka Loko], Kalihiwai, Stone Dam, Puʻu Ka Ele, Morita, and Waiakalua. This is a relatively small reservoir network compared with other plantations of this time.

Ka Loko was the largest reservoir on the plantation. Ka Loko’s ditch had a “major reconstruction” in 1912 and was 16,470 feet long. The maximum capacity of Ka Loko is more than 408,000,000. gallons. Ka Loko source was Puʻu Ka Ele Steam.

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107 This handwritten KSP document lists an additional dam that is not legible. Kilauea Sugar Plantation Records, report entitled: “Water in Reservoirs” (July 1910- June 1911), Kauaʻi Historical Society.
108 H.W. Thomas Album, Kilauea Sugar Plantation, 21-22 (early 1900’s), Hawai‘i Historical Society.
111 Id. at 84.
112 Id.
The reservoir was fed by Ka Loko and Moloaa ditches.116 From Ka Loko Reservoir the water continued down in three directions, with the main ditch going to Morita Reservoir.117 One ditch drained to Waiakalua Reservoir. Another drain went to Koʻolau Reservoir and water from Koʻolau Ditch was pumped back to Koʻolau Reservoir for use in irrigating the fields. Most of the water was used to flood Kilauea’s cane fields. The one exception was Kalihiwai, known as “Drinking Water Reservoir”, which had an 8-inch pipe that supplied Kilauea town with water for domestic use.118

4.4 Kilauea Sugar Plantation’s Management

KSP was a highly organized operation with a number of departments and extensive management system. This is an example of the infrastructure Hawaiʻi’s sugar plantations had to support the operation, monitoring and maintenance of their dams and water systems. This intricate system of management and maintenance is not in place today to maintain the old plantation water structures which continue to be used.

Kilauea had a head manager and specified departments addressing all aspects of the plantations’ production and life. This included Industrial Engineering, Field, Office, Industrial Relations, Factory, Automotive, Warehouse, Carpenter and Medical departments.119 There were clear job descriptions and cultivated community partnership in the work. In 1959, Kilauea had 35 full-time staff managing different departments. Fifteen of these men were managing the field work and also helped with plantation water

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116 “Ka Loko Reservoir was fed by the Koloko and Moloaa ditches.” Carol Wilcox, Sugar Water: Hawaiʻi’s Plantation Ditches, 85 (1996).
system maintenance. In addition to a Field Superintendent, there were also two Irrigation Supervisors, two Irrigation Foremen, and two Weed Spray Foremen.\textsuperscript{120}

The company produced an annual report evaluating the state of the water works, cultivation and other plantation conditions. The categories described included; weather, irrigation, planting and varieties, crop production, fertilization, weed control, rat control, factory, capital expenditures, equipment rental budget, land matters, health and safety, industrial relations, training and staff changes.\textsuperscript{121} It is significant to note that these documents also accounted for maintenance, repairs and improvements that were conducted on the irrigation, reservoir, and dam structures, as well as, repairs that were needed. Along with the yearly plantation reports, the parent company, C. Brewer produced a yearly financial review. This described the plantations income, expenses, assets, debits, liabilities and capital shares, as well as, a list of employees. The detailed accounting delineated different areas of expense, including the annual amount of money spent on the plantation’s irrigation system.

\textsuperscript{120} Kilauea Sugar Company, Limited, Annual Report, December 31, 1959.
\textsuperscript{121} Kilauea Sugar Company, Limited, Annual Report, 1961.
5  Ka Loko Dam and Reservoir

5.1  Construction, Limitations and Improvement of Ka Loko

Ka Loko as originally constructed in 1890, may have been an earth-rolled dam. The dam and reservoir were a part of the larger system of ditches, tunnels and flumes that constituted Kilauea’s water systems. As previously mentioned, Ka Loko was primarily fed by surface run-off water from rain, and the reservoir’s water level fluctuated significantly corresponding with yearly rain-seasons and occasional droughts. Kilauea Sugar Plantation struggled with the inconsistent availability of water for irrigation.

To have a more reliable water source, the KSP directors decided to expand Ka Loko’s water capacity and thereby enable a greater reserve of water. The 1911 Annual Report states; “Lack of water [for regular irrigation of all cane fields] has always been a serious handicap to this plantation, and with the….improvements, we will plant our crops with more assurance than heretofore.”\(^{122}\) Both Ka Loko Reservoir and Stone Dam were authorized for enlargement by the company’s directors and the work started in 1911.

Photographs taken at Kilauea Sugar Plantation during the engineered expansion display men “sluicing Ka Loko,”\(^{123}\) the method used to construct hydraulic fill dams. To increase the reservoir’s height and length, the hydraulic fill was added to the original structure. If the existing dam was, in fact, an earth-rolled dam, the added hydraulic fill mantel over it, transformed Ka Loko into a hybrid rolled earth-hydraulic fill dam. As previously discussed, during the 1911/12 era, hydraulic fill was understood to be an

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\(^{122}\) At this time, John D. Spreckels, A.B. Spreackels, W.G. Irwin, Henry E. Bothin and W.D.K. Gibson are the Directors of the company. Kilauea Sugar Plantation Company, Annual Report, 7 (December 31, 1911).

\(^{123}\) Mr. and Mrs. H.W. Thomas Album, Kilauea Sugar Plantation, 23-24, 31, 41 (early 1900’s), Hawai’i Historical Society.
economical method of dam building. “A couple of decades later earth moving equipment had become efficient enough to make hydraulic fill methods, with their safety shortcomings a much less favorable option.”124 Later, it was recognized that this is not a good method for dam construction in areas close to seismic activities because earthquakes can cause the liquefaction of the soil.125

During the renovation, Ka Loko Dam was raised to 750 feet above sea level. The reservoir’s capacity was increased by 140,957,000 gallons.126 At the completion of Ka Loko Dam and reservoir’s improvement, Kilauea Sugar Plantation’s 1912 Annual Report states: 127

Permanent Improvements

KOLOKO RESERVOIR: The enlargement of this dam was started and completed during the past year. The dam has been greatly strengthened, and raised 12 feet, which is calculated to increase the capacity by 146 million gallons. Owing to the added strength of the dam, I am confident that it will hold 200 million gallons more, or a total capacity of 500 millions. The ditches which supply this Reservoir with storm water have been enlarged, and are capable of filling the reservoir in three days.128

Two years later, a 1914 Kilauea Plantation diagram displays the reservoir gate valve, concrete profile, and cross sections of Ka Loko Reservoir tunnel. This is an early

124 Personal Communication: Terry Reynolds, Michigan Technological University, November 27, 2006.
125 Id.
127 Kilauea Sugar Plantation records state the total cost of the dam’s renovation including the dam and gate was $9642.92 (equating $64.30 per mil. Gal increase). This document lists: “Material, Loco., Land and Ship, Stables, Labor, Skilled, Manag’mt” needed for the work on “Flumes, Ditches & Tunnels, Sluicing, Prepar’ Found’n, Powder, Tools & Miscel”, Kilauea Sugar Plantation Records, report entitled: “Analysis of Cost of Koloko Dam”, Kaua’i Historical Society.
example of Kilauea Plantation’s use of concrete in the construction of their Ka Loko water system.  

Ka Loko’s spillway was originally made of compacted earth. The trucks and tractors that drove over this section of the embankment would sometimes go through overflow water. Concrete was put in the spillway around the 1950’s to help prevent the trucks and tractors from digging up the earth or getting stuck in the spillway.  

5.2 Plantation Water System Maintenance and Ka Loko 

Because water was precious during the sugar era, plantations carefully monitored their ditches, dams and reservoirs. An early Honolulu Advertiser journalist described how the cost of a plantation’s ditch systems could be evaluated by the number of men that were required to maintain them.

The Olokele ditch is thirteen miles long, three-quarters being tunnels. The Hanapepe ditch is also thirteen miles long, with only two or three short tunnels and several miles of flumes. All of the upper Olokele system, from the intake far up in the mountains, is underground down to the 1400 foot level.

The physical difference in the two systems makes the Olokele water cheap and the Hanapepe water dear. One requires only four ditch tenders while the other often calls for the employment of large gangs of men to keep the flume and open ditches in repair.

Kilauea Sugar Plantation also kept track of the number of men needed to maintain and run the irrigation systems. From April 1935 to June 1936 the approximate number of men needed to irrigate a field ranges from four to 11 and a half. 

130 Witness Interview, Jack Gushiken (December 7, 2006).
131 Jared G. Smith, “Plantation Sketches: A Record of Hawaiian Industries as They Appeared to an Itinerant Journalist in 1923; Published in the Columns of the Advertiser, 30 (1924).
Plantation records at Kaua‘i Historical Society have extensive documentation of ditch and reservoir monitoring. One to three times a day a man would read and record the reservoir levels and observe the weir readings that recorded the ditch flows (measured by how many millions of gallons flowed through the ditch per day).  

In addition to Kilauea Sugar plantation’s documentation of daily maintenance and repairs of their water system, early 1900 photographs show cleared embankments around Ka Loko Reservoir. During the plantation days it was vital to keep the ditches, reservoirs and dams clear of trees and shrubs and to clear out accumulated silt in the tunnels. Keeping irrigation structures in good shape and repairing flumes enabled the water system to function smoothly and maintained the integrity of the spillway, dam banks and ditches. In addition to regular clearing of the ditches for any fallen trees or vegetation, herbicide was used to prevent shrub and tree growth and debris was shoveled out to increase the flow rate of the water.

Early KSP photographs show few trees, but there are several photographs showing gangs of men “grubbing trees” and “Clearing trees”. The picture of Kilauea Sugar Plantation “Main Ditch”, has no trees, shrubs, or tall weeds growing on its banks, only short and manicured grass. Another photograph shows a “gulch contractor” clearing the gulch, and pictures taken around Waiuli Dam (one entitled “Scrapers at work

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133 The five year average M.G.D. capacity and flow are recorded. Kilauea Sugar Plantation record about ditch systems entitled: “Kilauea Sugar Plantation Company” (“1949-1953”) Kaua‘i Historical Society. Kilauea Sugar Plantation kept extensive documentation on the plantation infrastructure, improvements and management issues. The amount of records that exist are beyond the scope of this report. Salvaged records can be found in the Kilauea Sugar Plantation Records located at the Kaua‘i Historical Society, Lihue, Kaua‘i.

134 Mr. and Mrs. H.W. Thomas Album, Kilauea Sugar Plantation early 1900s at 23, 24, 31, 47, 58, 59. Hawai‘i Historical Society.
135 Id. at 9-10.
136 Id. at 24, 26.
137 Id. at 18.
Waiuli Dam”), and at “Stone Dam Outlet” do not show large vegetation or overgrowth. \(^{138}\)

Regular maintenance for the plantation’s water system was critical and required a number of workers. This work prevented the dams, ditches and reservoirs from having seepage due to root damage in the embankments.

### 5.3 Ka Loko Dam’s Historical Water Levels

The historical strength of Ka Loko is demonstrated in the records that show that numerous times the dam was quite full, at times holding its maximum capacity over extended periods. Following the reconstruction of the dam, the maximum depth of the reservoir was 43 feet. In 1914 the records show that; on January 27\(^{th}\) the reservoir head was at 38. feet, on April 14\(^{th}\) the reservoir head was at 39.1 feet and on May 5\(^{th}\) the reservoir reached 40.1 feet. \(^{139}\)

Between 1940 and 1954 Ka Loko Reservoir reached its 43 foot maximum capacity twenty different times. Listed below are the years and number of days that the reservoir held its maximum capacity; \(^{140}\)

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Days (Month) Reservoir at Maximum Capacity (43 Ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1942</td>
<td>9 Days (April)</td>
</tr>
<tr>
<td>1943</td>
<td>8 Days (March); 7 Days (April); 18 Days (May); 1 Day (June)</td>
</tr>
<tr>
<td>1946</td>
<td>5 Days (February); 2 Days (April); 3 Days (December)</td>
</tr>
<tr>
<td>1947</td>
<td>1 Day (January)</td>
</tr>
<tr>
<td>1948</td>
<td>5 Days (January)</td>
</tr>
<tr>
<td>1949</td>
<td>12 Days (February); 4 Days (March)</td>
</tr>
<tr>
<td>1950</td>
<td>4 Days (April)</td>
</tr>
<tr>
<td>1951</td>
<td>10 Days (March); 19 Days (April)</td>
</tr>
<tr>
<td>1952</td>
<td>24 Days (January); 6 Days (February); 22 Days (March); 8 Days (April)</td>
</tr>
<tr>
<td>1953</td>
<td>31 Days (March)</td>
</tr>
</tbody>
</table>

\(^{138}\) Id. at 18, 14-15, 52.


These records demonstrate that Ka Loko had a performance history of maintaining its maximum capacity over an extended period of time. March of 1953, the dam held its 43 ft maximum for an impressive thirty-one day period. Additionally, the alterations in reservoir depth reveals that the reservoir and dam were able to resist repeated intermittent soakings with water and the swelling and shrinking that would occur with these changing conditions.

5.4 Closure of Kilauea Sugar Plantation

C. Brewer announced plans to liquidate sugar operations at KSP on January 27, 1970, and finally closed KSP on December 31, 1971. The closure of the plantation brought with it many changes;

[W]hen Kilauea Plantation closed, local and state government, along with agent C. Brewer and individual farmers, began to search for alternative agricultural options. Besides cattle, which had long been an industry in this area, papaya, guava, prawn ventures, and agricultural subdivisions were established with the expectation of being able to use the Kilauea water system. However, no mechanism was established to secure the easements or maintain the old system. Over the years the connections between reservoirs and delivery systems were destroyed by roads, pasture, development, neglect, and intent….Puu Ka Ele and Koloko reservoirs’ delivery systems were gone. C. Brewer established Kilauea Irrigation Company, a public utility, to administer the surviving sections that service its guava farming operation. By the mid-1990s, some reservoirs stood alone with little utilitarian purpose.

When Kilauea Sugar Plantation ceased its sugar operations, there was not a well established plan in place to determine the best uses of the land or a crew of people in

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place to maintain the old water system. Eventually, most of the plantation’s land was subdivided and sold.\textsuperscript{143}

6 Hawai‘i Water Systems and Dams Constructed Prior to 1970

Many of the early dams and water systems continue to be used today to provide water and electricity.\textsuperscript{144} For example, on Kaua‘i, 80-100 year old plantation water infrastructure still constitutes a good portion of the Department of Water’s systems.\textsuperscript{145} On Maui, the East Maui Irrigation System (EMI) started with Old Hamakua Ditch built around 1876 and expanded by private investment with nine more ditches up to 1923. There are 74 miles of tunnels, inverted siphons, flumes, ditches of this system that still “convey 62 billion gallons per year from steep tropical forested watersheds with high rainfall on the Windward side of Haleakala to the semi-arid Maui isthmus for sugar cane cultivation.”\textsuperscript{146}

One hundred and sixteen dams on Hawai‘i’s DLNR Dam database were constructed before 1970.\textsuperscript{147} Twenty-two dams on this list were constructed between 1910 and 1913, close to the completion of Ka Loko Dam’s renovation in 1912. Because of the extensive collaborative sharing of engineering techniques between Hawai‘i’s plantations, it is possible that other dams were constructed in a similar manor to Kaloko dam, using

\textsuperscript{144} For example, H.P. Faye’s major engineering projects, the Waimea ditch and Pu‘ulua Reservoir and Koke‘e ditch system on Kaua‘i are still in use. Information posted about Sugar Pioneer H.P. Faye in Sugar Plantation exhibit at Kaua‘i Historical Museum, October 25, 2006.
\textsuperscript{145} The DOW’s 2020 water plan refers agriculture and stream water or watershed management to the State and other agencies. http://www.kauaiwater.org/ce_waterplan2020.asp.
\textsuperscript{146} http://www.asceHawaii.org/landmarks.html.
\textsuperscript{147} Department of Land and Natural Resources, Dam Database.
the hydraulic fill method. As mentioned earlier, hydraulic fill and other earthen embankment dams are especially dangerous in areas that have seismic activity.148

Hydraulic fill was still being used as a method of constructing dams in Hawai‘i in 1931. As previously mentioned, Alexander Dam on Kaua‘i was both constructed (1927) and reconstructed (1931) using the hydraulic fill method. According to the DLNR list between 1885 and 1931 one hundred dams were constructed in the Islands. This list only contains the one hundred and thirty-three dams with National ID’s that are (or were) regulated by the DLNR. A number of reservoirs are privately owned. For example, of the dams and reservoirs on Kaua‘i, thirty-seven are privately owned. Seventeen are state agencies. It is possible that old plantation dams were later renovated and/or expanded using the hydraulic fill method similar to the work done at Ka Loko Dam.

7 Conclusions

In 1996, based on her studies of sugarcane irrigation systems, Carol Wilcox summarized several of the pressing economic and social questions about Hawai‘i’s water:

One forum for debating this future [of water and old plantation irrigation systems] is the Commission on Water Resource Management, guided by the 1987 Water Code. Today the Water Commission must entertain new standards and conservation ethics when determining water allocation. It must consider an entire new vocabulary, in fact, much of which is not clearly defined in the context of water management in Hawai‘i, such as traditional and customary Hawaiian rights, protection and procreation of fish and wildlife, ecological balance, scenic beauty, public recreation, beneficial instream uses, and public interest. Hawai‘i’s government and people, therefore, are facing big questions:.....

Who will be responsible for maintaining (or dismantling) the ditches, reservoirs, dams, and tunnels? Who will shoulder the liability? Who will bear the cost: users or taxpayers? How can water best be used to support continued watershed for urban use? Will water rights grounded in ancient Hawaiian law and tradition be claimed and honored? How will water

148 See Appendix B, Report of Dr. Lelio Mejia.
conservation efforts and “best management practices” fare? Will stream restoration ever be practicable? ¹⁴⁹

More than a decade later, these questions surrounding Hawai‘i’s old plantation surface water irrigation systems remain, and the challenges of properly maintaining or dismantling them remain daunting.

¹⁴⁹ Carol Wilcox, Sugar Water: Hawai‘i’s Plantation Ditches, 9 (1996).