HISTORIC AMERICAN ENGINEERING RECORD

KALAUPAPA WATER SUPPLY SYSTEM

HAER No. HI-42

Location:	Waikolu valley and Kalaupapa vicinity, Island of Molokai, Maui County, Hawaii
USGS Quadrangle:	Molokai East, Hawaii (11 x 18-minute series)
UTM Coordinates:	2/70900/234500 - 2/715150/2340350
Date:	1873-1983
Present Owner:	State of Hawaii
Present Use:	abandoned
Significance:	From 1866, Hawaiians suffering from the severest forms of leprosy were exiled to the peninsula of Kalaupapa on northwest Molokai. A beautiful, windswept area, it lacked a readily available supply of potable water, which had to be transported from nearby valleys watered by streams draining topside Molokai or themselves receiving abundant annual rainfall. A pipeline initially designed to capture runoff from nearby valleys proved inadequate, and periodic droughts encouraged extension of the system to tap the abundant springs and runoff of the Waikolu valley several miles distant from Kalaupapa. During the twentieth century, this system was enlarged and extended several miles up the valley, to an elevation of approximately 560 feet. By the late 1930s, the system provided a regular supply of pure, if mildly acidic water that was treated by aeration and sedimentation as it flowed down the valley. Built and modified by the Territory (and then State) of Hawaii, strenuous and difficult regular maintenance was performed largely by patients
Historian:	Richard O'Connor, 1998

Introduction

Kalaupapa, the Hawaiian colony for patients with Hansen's disease, or leprosy, was established in the nineteenth century on a small peninsula jutting from the rugged northern coast of the island of Molokai. Swept by trade winds, lacking sheltered harbors, separated from topside Molokai by 2000' *pali*, or cliffs and, most important, without a readily available supply of potable water, the peninsula was selected by the Hawaiian government in 1865 as the exile site for those most seriously afflicted with leprosy. Unlike the settlements of non-afflicted Native Hawaiians it displaced, the Kingdom-sponsored colony from its inception offered little but a hard, nearly self-sufficient existence to patients. As the patient population grew and standards for the care and treatment of leprosy rose, the settlement spread across the peninsula from the initial cluster of inhabitants in Kalawao, on the eastern side, to include hospitals, visitors' cottages, recreation areas, schools and numerous houses and dormitories comprising the settlement of Kalaupapa on the western third of the peninsula[1].

From the establishment of the first colony, undependable and inadequate supplies of fresh water on the peninsula and in the closest valleys were some of the biggest problems facing patients. The peninsula received little rain, and ground water tended to be brackish, unlike the fresh water of topside Molokai. Consequently, throughout the nineteenth century, the primary settlement at Kalawao obtained fresh water from valley streams that cut deep gorges through the *pali* in the immediate vicinity.

The streams of the Waihanau and Waialeia valleys were the closest and most directly accessible to the peninsula. In 1906, geologist Waldemar Lindgren measured flow at the upper levels of the streams and concluded that the Waihanau "can be relied on for 3,250,000 gallons per twenty-four hours (5.03 cubic feet per second) from November 1 to June 1, for 1,000,000 gallons (1.55 cubic feet per second) from June 1 to August 1, and for at least 100,000 gallons (0.15 cubic foot per second) from August 1 to November 1." The Waialeia was considerably smaller, with an average "flow of 400,000 gallons (0.62 cubic feet per second) from November 1 to June 1."[2] Source water came from "high-level ground water impounded between volcanic dikes...(or) perched on ash layers or other poorly permeable horizons," that was released when "cut into and intercepted" by stream channels. Dry weather stream flow depended on the extent to which these stream channels cut into the *pali* and intercepted reservoirs. Of the valley streams closest to the peninsula, the Waihanau cut the least and the Waialeia somewhat more; the Waikolu, several

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[1]Linda Greene, *Historic Resource Study: Exile in Paradise* (U.S. Department of the Interior, National Park Service, 1985), pp. 25-43.

[2]Waldemar Lindgren, *The Water Resources of Molokai*. U.S. Department of the Interior, Geological Survey (Washington, DC: GPO, 1903), p. 31; Greene, *Exile,* p. 85.

miles east across tide-swept volcanic boulder beaches, cut the deepest. The Waialeia did not run in the lower valley in the summer, and water from the Waihanau, the stream closest to the Kalaupapa Peninsula, sank into the ground by the time it reached lower levels during dry weather. Until 1873, patients at the Kalawao settlement obtained fresh water for drinking, cooking and bathing from the upper Waialeia valley, and transported it back to the settlement in cans.[3]

The demand for water rose as settlement population grew and agricultural activities increased. Between 1870 and 1873, settlement population more than doubled, to 810 patients, and doubled again between 1886 and 1890, when it reached its historic peak of 1213. (See Appendix A) In addition to patients, medical and religious personnel and *na kokua*, non-leprous helpers related to patients, also lived on the peninsula. Additional water was needed for cooking, bathing and laundry, as well as for cultivating taro and raising livestock, vitally important activities for residents who raised much of their own food supply and small cash crops.[4]

The water supply system at Kalaupapa was constructed and reconstructed at least four times between 1866 and 1998. Construction and maintenance, usually considered separate, sequential tasks, were almost indistinguishable for the Kalaupapa supply. During routine maintenance, of which there was a substantial amount, parts of the system were often constructed using different designs and materials. Some modifications were more significant than others, resulting in a gradual transformation of the system from a short, narrow line from the Waialeia valley to Kalawao, to a five mile combination 8" cast-iron pipe and concrete pipe and flume system reaching from the upper Waikolu valley to Kalaupapa.

Local Water

The first water system was constructed in the summer of 1873, after the Board of Health provided for a still extant reservoir and some pipe for the Kalawao settlement. Relieving residents from the arduous task of carrying water long distances over difficult terrain, the improvement over existing conditions was remarkable. According to Father Damien, "Kalawao has been well supplied with good water for drinking, bathing and washing, and has proved to be

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[3]Kiyoshi J. Takesaki, "Ground-Water Conditions in the Waikolu-Kalaupapa Area, Molokai, Hawaii," (unpublished draft report, Denver Service Center, Technical Information Center, 1982).

[4]President of the Board of Health, *Report* (Honolulu, HI: 1921), pp. 39-40 (hereafter, Board of Health, *Annual Report)*; Superintendent of the Leprosarium at Kalaupapa, *Monthly Report*, August, 1939; June, 1945; July, 1945 (hereafter, Superintendent, *Monthly Report*); Greene, *Exile,* p. 163.

a better place for living than Kalaupapa, where the people continue to resort to rain or brackish water, and in dry seasons they are obliged to come to Kalawao...."[5] In 1886, Fr. Damien suggested that piping water from the Waihanau Valley to Kalawao would be easier and cheaper than piping it from Waikolu, an alternative evidently under consideration. The same year, the Board increased pipe-line diameter, replacing much of the 1" supply pipe, possibly with 2" and 1-1/2" as recommended by Fr. Damien.[6]

Tapping the Waikolu

By the mid-1880s, when the Waialeia and Waihanau valleys, which had supplied Kalawao's water from its earliest years as a leprosy settlement, no longer provided sufficient quantities for the growing population, officials seriously considered piping water from a more distant source, the Waikolu valley. The area drained by the Waikolu stream, approximately one mile from the eastern border of the Kalawao settlement, was locally renowned as a well-watered, if somewhat inaccessible, valley surrounded by densely forested *pali*. A taro cultivation area favored by native inhabitants since the early nineteenth century, weather patterns and topography created "showery conditions" most of the year, with heavy, torrential rains in the winter season.[7] Water from Waikolu was piped initially from the Notley springs, located a short distance up the valley on the eastern *pali*. The springs ran continuously, guaranteeing a steady supply of water, and surfaced at the lava bench between 380' and 420' above sea level, assuring sufficient pressure to drive water over the nearly 300' peak elevation between Waikolu and Kalaupapa. The lower Waikolu stream contained a potentially larger supply, estimated at one million gallons per day, but was too low to generate sufficient head to move the water over the Makanalua divide. The upper Waikolu valley contained "a practically unlimited supply," the availability of which was "simply a question of pipe and elevation."[8]

As Waikolu became the primary water source for Kalawao and the growing settlement at Kalaupapa, a substantially longer and larger pipeline was constructed. Pipe installed in the late 1880s was 4" diameter, the Board noted in 1894, "not large enough to supply all the demands, and this pipe after reaching the village of Kalawao is reduced to a 3" pipe and further on to 1" or

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[5]Fr. Damien, "Report on Water Supply at Kalawao," March, 1886, p. 9 (Board of Health, Box 35, Hansen's Disease: 1873-1887; Correspondence).

[6]Board of Health, *Report,* 1890, pp. 142-3; Greene, *Exile*, p. 158; Fr. Damien, "Report," p. 9.

[7]Lindgren, *Water Resources*, p. 31; Greene, *Exile*, p. 85.

[8]Board of Health, "Water System for Leper Settlement," July 23, 1906 (Board of Health, Correspondence: Water Supply, Kalaupapa, Box 35).

2"."[9] The Board recommended in 1898 the installation of 2200' of 8" cast-iron pipe line to the Waikolu spring, probably at Notley, at a projected cost of $19,900, including connecting 3" and 4" distribution pipes and relaying mains at Kalaupapa. In addition to the Notley springs, a small basin or reservoir was cut and two 3" pipes laid to the main 8" supply line. Buried wherever possible beneath soil or rock to protect it, the 8" pipe arced down the *pali*, crossed the Waikolu valley, then ran west at the base of the sheer, 2000' oceanside *pali* along the boulder beach, up the gulch and onto the peninsula at Kalawao. At Kalawao gulch, the 8" pipe branched off into a 6" line that ran to Kalaupapa, and a 4" line that fed Kalawao and the Koloa reservoirs before rejoining the 6" line. At Kalaupapa, the 6" line terminated at Kapiolani Street and Damien Road, where a 4" line led to Beretania Hall and then reduced to 2" for further distribution. In addition, a double line of 3" and 2" pipe ran to the Bishop Home and then reduced for further distribution.[10]

Extending the pipeline to the Waikolu valley along the boulder beach initiated maintenance problems that plagued the settlement for nearly a century, until the current system was installed in the 1980s. Periodic violent storms pounded the line with both waves and boulders. Stones broke loose and fell from the *pali* precipice, smashing the pipe and breaking joints. Severe Kona storms, such as that of January, 1916, overturned buildings throughout the settlement and broke the pipeline in numerous places. Earthquakes triggered landslides that caused numerous breaks and required immediate attention under hazardous conditions. A ten-ton rock loosened by rain broke three pipe lengths in 1942, and took three days to repair. Landslides also blocked the beach and had to be cleared to facilitate access to the Waikolu valley.[11] The beach pipeline continued to present problems until the new system was finally installed in the 1980s. Edwin Lelepali worked on the line in the 1960s and 1970s, and recalls making routine repairs in breaks caused by falling boulders and landslides. His experiences highlight the perennial difficulties the line presented, and the extent to which settlement administrators tried to modify the system to protect it and ease repairs. After determining that the buried beach pipeline was not sufficiently protected from breakage and was too difficult to dig up and repair after each incident, the settlement administration in the late 1960s ordered the beach segment excavated and mounted on concrete stanchions. Wood walkways were built atop the stanchions to facilitate pipeline access and travel across the rough beach. But according to Mr. Lelepali, the new arrangement left the pipeline more vulnerable to damage from landslides and storms, and pipeline repairs increased

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[9]Board of Health, *Annual Report*, 1894, p. 5.

[10]Board of Health, *Annual Report*, 1898, pp. 9, 66-67; Board of Health, "Water System," July 23, 1906.

[11]Board of Health, *Annual Report*, 1916; Superintendent of Kalaupapa, *Annual Report*, 1937-8, p. 3; Superintendent, *Monthly Report*, November, 1935.

after it was raised. Another attempt in the 1970s, to make quick repairs with PVC pipe, failed when the plastic pipe could not withstand the waterline pressure.[12] Ultimately, the settlement never developed a method of fully protecting the beach portion of the Waikolu pipeline.

Damage to the pipeline was so regular and so severe that the Board recommended in 1894 the construction of a reservoir between Kalawao and Kalaupapa to help the settlement through brief periods when the pipeline was damaged and under repair. A site was selected on high ground between the two settlement areas, and two stone reservoirs were built. The smaller one held 50,000 and the larger one 150,000 gallons. Tank construction reflected local conditions. Lack of funds for the settlement in general mandated the use of cement-covered local stone, while the difficulty of digging into volcanic rock meant that the tanks would be above ground, but not too high to create back pressure into the system. To prevent the stone walls from bulging, earthworks were built up surrounding the tanks. Both reservoirs are intact. In 1904, a "new 10,000 gallon tank at Makanalua...helped the middle district"[13] and, in 1931, this was replaced by a 750,000 gallon steel tank, raising storage capacity to over one million gallons. Reservoir levels were maintained near full at all times to accommodate settlement needs during droughts and periods in which the supply from the valley was disrupted. During periods of heavy rainfall in the valley, lines were opened, the reservoirs emptied and the system flushed under pressure. Reservoir water was aerated intermittently by overflow. Reservoir maintenance, including scraping and painting the steel tank and making roof repairs, was routinely performed when conditions permitted. Both Edwin Lelepali and Joseph Mollena remember the arduous work of shoveling out sediment and then greasing the inside of the steel reservoir.[14]

Issues of access for routine maintenance, cleaning and repair gained in importance as the pipeline was extended. Widely varying terrain--the boulder beach below the sheer 2000' *pali*, steep hillside paths up the valley, well-saturated spring-fed marshland, dense taro and ginger undergrowth, difficult stream crossings--created challenges to simple foot transportation, but when coupled with the necessity of hauling equipment and supplies, became daunting. These

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[12]Interview by Sharon Brown, NPS Historian at Kalaupapa National Historic Site, with Edwin Lelepali and Joseph Mollena, Kalaupapa, Hawaii, December 14, 1998.

[13]Board of Health, *Annual Report*, 1890, p; 143; 1894, p. 5; 1904, p. 73; Department of Public Works, Territory of Hawaii, engineering drawing PW4175.2, Sept., 1930.

[14]Superintendent, *Monthly Report*, August, 1934; January, 1935; April, 1935; January, 1936; November, 1936; Greene, *Exile*, p. 462. Reroofing in 1939 included modifications "making these units rat proof..." Superintendent, *Monthly Report*, January, 1939; Interview by Sharon Brown, NPS Historian at Kalaupapa National Historic Site, with Edwin Lelepali and Joseph Mollena, Kalaupapa, Hawaii, December 14, 1998.

obstacles were magnified by the effects of frequent and severe storms. Trail maintenance involved clearing the results of numerous landslides, the most difficult of which were at the base of the *pali* and required cutting through mounds of boulders and smaller rock. Further up the valley, the necessity of making repairs, even when inclement weather persisted for days, made repair work difficult: in 1935, the Superintendent noted that "heavy rainfall continuing and streams in flood to such an extent as to make it necessary to haul men and horses across with lines."[15]

Extending the System, 1908-1937

Construction of the United States Leprosy Investigation Station (USLIS) at Kalawao in 1908, spurred extension of the water system. Initially, the 8" inch cast-iron pipeline was carried to the 480' elevation, approximately 4.5 miles from Kalaupapa. The agreement between the Federal government and the Territory of Hawaii provided the USLIS with 4.5 acres of land surrounding a spring in the Waikolu valley as a potential source of water.[16] To assure an adequate supply, the initial decision to connect the USLIS to the existing 8" water line was re-evaluated. According to project engineers, "(T)he proposed extension of 8 inch main was designed to get a direct supply from the river and to carry a full load of water over the reservoir summit to the Kalaupapa Settlement, there being an inadequate supply from the springs during the dry seasons." The territorial legislature appropriated $15,000 in 1905 and $12,000 in 1907 to extend the 8" cast-iron pipe line "to the head of the valley." There, it connected to an intake ditch that was part of "a diverted water course constructed by the primative (sic) inhabitants, possibly over 100 years ago for growing 'Kula' taro."[17] In exchange for 200,000 gallons of water daily, the USLIS paid the remaining expenses. When the work was finished in 1909, the Board of Health considered the supply to be "amply large to meet any demand made within the immediate future."[18]

The Notley spring/catch basin system was considerably enlarged during construction of the USLIS. Each of the three catch basins was built into the lava bench, with the *pali* forming the back wall, and concrete walls 1' thick and 2' deep forming the basin on the other sides. Spring No. 3, fed by multiple springs and streams, was the largest and the initial source for the 8" supply

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[15]Superintendent, *Monthly Report,* February, 1935.

[16]Greene, *Exile*, p.258.

[17]Engineering drawing, "Map of East Side of the Leper Settlement," No. 1619 1, Sept., 1906, (tracing, May, 1908).

[18]Board of Health, *Annual Report*, 1905, p. 7; 1907, p. 139; 1909, p.193 (quote); Greene, *Exile*, pp. 272-273.

pipe, which sat in a 2' x 2' x 2' intake sump. A large hole was blasted in the catch basin to facilitate interception of percolating veins. At Spring No. 2, holes were blasted into the *pali* and 4" pipes inserted to increase the supply of water to the catch basin, which was fed primarily by the spring located some distance away, from which water was delivered in a 4" pipe. Two 4" pipes drained the basin to the 8" main. Spring No. 1 was the smallest; a single 4" pipe connected this spring to one of the pipes draining Spring No. 2. Notley provided an alternative, rather than a complementary, supply: an attempt in 1935 to augment water to the settlement by combining Notley and flume supplies failed after "the flume supply exerted a slow but very perceptible back pressure into the Notley basin," a condition predicted by "old water-tenders in the Settlement."[19]

By 1912, the extended water system no longer supplied the needs of either Kalaupapa or the USLIS, and the line was extended up the valley. Dry weather, which had plagued northern Molokai for two months early in 1912, generally provoked scarcities for all water systems that took their supplies from springs, streams and runoff. At Waikolu, the use of an old taro irrigation ditch to feed the pipe exacerbated the effects of the drought. As the ground in the valley dried out, the 2200' spring-fed ditch absorbed enough water to cause shortages in the settlement. Moreover, the Board felt that water from the ditch was unsanitary and that the flume would provide a cleaner supply. The Board decided to construct a wood flume from the end of the 8" pipe toward the Waikolu valley water head. The flume emptied water into a drainage basin, where it passed through strainers before entering the 8" pipe. Finished the following year, it measured 14" x 20" in section and replaced 1900' of ditch, at a cost of $750. By 1929, when it was completely rebuilt during the months of July and August, this flume reached 2800' up the valley.[20]

An improvement over the irrigation ditch, the wood flume nonetheless needed constant maintenance and repair, and soon became the source of considerable water loss. In 1921, only eight years after it was built, the flume and system delivered only 100,000 gallons per day to the Settlement, one-half the amount guaranteed the USLIS under the 1908 agreement! During the next year, the flume was completely rebuilt; despite repeating the exercise in 1928, at a cost of $2,000, by February of 1936 the flume was once again "practically beyond other than emergency repairs."[21] Heavy rains regularly washed uprights clear of footings and knocked out sections, and filled the open flume with debris. Cleaning out the flume was hard work, requiring the removal

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[19]Engineering drawing, "Map of East Side of the Leper Settlement," No. 1619 2, Sept., 1906, (tracing, May, 1908); Superintendent, *Monthly Report*, 8/35.

[20]Board of Health, *Annual Report*, 1912, pp. 161-2; 1913, p. 111; 1929, p. 218; Superintendent, *Monthly Report*, February, 1937.

[21]Board of Health, *Annual Report*, 1921, pp. 39-40; 1929, p. 218.

of wood covers and flushing out accumulated debris. The flume provided a favorable environment for the growth of vegetation, which had to be cleared periodically, and for the prolific growth of "limu," a local moss that broke off in quantity and clogged the strainer, sometimes requiring daily cleaning.[22]

Rebuilding the System: 1937-1938

In 1937, the Board of Hospitals and Settlement began a fifteen month reconstruction of the Waikolu water supply system. The effort was remarkable for several reasons. According to the superintendent, it "constituted the only work of this permanent character performed on the system since its installation about forty years ago, except occasional repairs of breaks in flume or pipe." (The superintendent erred by about a decade. This was the first reconstruction of the water system since it was extended into the valley during the construction of the USLIS in 1908.) Second, the new system incorporated important features that improved the quality of the water captured in the valley and sent to the settlement. Finally, the use of "Hume" concrete pipe and cast-iron pipe in place of wood flumes suggests an attempt to ameliorate the regular and at times significant damages to the system caused by torrential winter rains.[23]

In addition to the flumes, the redesigned system included a relatively sophisticated new water intake. The simple dam, screen and culvert configuration reflected local conditions--frequent rainfall, ample shading, constant temperatures, and the modest demands of a small settlement. A diversion weir blocked the ditch that had diverted water from the main stream to the old flume, creating a small settling pool that helped stabilize the flow of water to the system and provided preliminary sedimentation. Built "of reinforced concrete, ten feet high at the center and 35 feet long," the dam channeled water through a 2' x 2' screen (made of galvanized pipe 1" or 1-1/4" in diameter set on 2-1/2" centers) and into a 2' x 2' concrete box culvert. The dam was also

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[22]Superintendent, *Monthly Report*, August, 1934; May, 1935; February, 1939; Interview by Sharon Brown, NPS Historian at Kalaupapa National Historic Site, with Edwin Lelepali and Joseph Mollena, Kalaupapa, Hawaii, December 14, 1998.

[23]Board of Hospitals and Settlement, *Annual Report*, 1938, p.30; *Annual Report of the Surgeon-General of the Public Health and Marine-Hospital Service of the United States for the Fiscal Year 1909*, in *Annual Reports*, 1901-1911, RG 90, National Archives.

Note: The description of the water system reconstruction is based in part on engineering drawings available at the Hawaii Department of Public Works. Plans and actual construction may have differed in detail.

equipped with a gate and 1' x 1' sluiceway.[24]

The new system replaced the wood flume along its entire length. On the upper portion of the headworks, from the intake to the aerator, water flowed through concrete boxed culvert; and from the aerator to the sedimentation chamber, it passed through 15" "Hume" concrete pipe.[25] Water emptied from the sedimentation chamber into new, 8" concrete "Hume" pipe. Unlike the flume, the box culvert and "Hume" pipe were "placed well against the slopes along which (the line) runs and is not vulnerable to slides that may occur above it." The superintendent considered this "a major advance in the water system."[26]

The surface runoff water collected in the Waikolu system likely contained impurities.[27] Four types of impurities that carry health hazards and contribute to discoloration, poor taste and odor commonly occur in runoff water: bacterial and other organic matter; materials in suspension; minerals; and dissolved gases. Waikolu water was considered to have a slight acidity that deteriorated iron pipes carrying water in the lower valley and across the beach below the *pali* and, with a pH of 6.8, compared unfavorably with water from Notley, which had a pH of 7.2.[28] Typical of runoff systems, Waikolu water contained particulates picked up as rain water

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[24]Board of Hospitals and Settlement, *Annual Report*, 1938, p. 30; Board of Hospitals and Settlement, engineering drawing, 1937, Sheet 4 of 4.

[25]"Hume" pipe was developed by the Hume Corporation of Australia. Patented in 1910, by the 1920s it was used throughout the world. "Hume" pipe was centrifugally cast in a revolving, horizontal mold. Concrete was poured into the mold and was compacted against the outer walls by centrifugal force. The process sprayed the concrete evenly around the inside of the mold, forming a non-porous, dense and exceedingly strong pipe. It is worth noting that the cast-iron pipe purchased for the Kalaupapa system in the 1930s was likely centrifugally cast as well, and shared the same characteristics.

[26]Board of Hospitals and Settlement, *Annual Report*, 1938, p. 31.

[27]Most water engineers acknowledge that "water that is absolutely pure is not to be found in nature." Ernest W. Steel, *Water Supply and Sewage* (NY: McGraw-Hill, 1938), p. 204. The contaminants discussed here are those generally found in runoff collection systems.

[28]Board of Hospitals and Settlement, Territory of Hawaii, *Annual Report* (Fiscal Year ending June 30, 1938), p. 30; Board of Health, 9/39. pH is a measure of the hydrogen-ion concentration depicting the strength of alkalinity or acidity. A pH value of 7 is neutral; values below 7 indicate acidity, and values above 7 indicate alkalinity. (Hardenbergh, *Water Supply*, pp. 275-7.) That the pH values for both Waikolu and Notley water hovered close to 7 suggests that there were only minor differences between the two supplies.

cascaded down steep valley walls to the valley floor.

The Kalaupapa water system, reconstructed in the late 1930s, both conveyed and treated water for the settlement. Water treatment involved removal of biological and mineral contaminants, primarily through aeration and sedimentation. At the time, aeration was commonly the first treatment given water collected from reservoirs and holding ponds. The overflow cascade aerator was located approximately 80' below the intake and dam and 130' above the sedimentation chamber. A concrete boxed culvert fed the aerator which, in plan, was 12'-0" long by 8'-8" wide, and consisted of six concrete steps that exposed water to the air in thin sheets over a fall of 7'-2". Aeration added oxygen and removed carbon dioxide, iron and corrosives, and was found particularly effective in reducing dissolved gases that caused noxious odors and tastes. Experimentation earlier in the twentieth century suggested that aeration had little or no effect on the removal of organic contaminates.[29]

After aeration, water flowed approximately 130' through 15" concrete "Hume" pipe to a continuous-flow sedimentation tank. In water systems, sedimentation removes suspended matter that renders water turbid, either by slowing down the flow of the stream (plain) or by the addition of coagulants such as alum (coagulation). Sediment was a particularly acute problem at Waikolu in light of the hard rainfall and the tendency for storms during the winter rainy season to wash vegetation, rocks and other sediment from the valley walls into the stream. Recommended solutions to sedimentation removal in the Waikolu valley were restricted by lack of space for an impoundment reservoir that would permit severe restriction of stream flow during high turbidity. "This is an especially valuable feature," note engineers F.E. Turneaure and H.L. Russell, "in the case of streams of moderate size where the high-water stage lasts but a few days," as in the case of Waikolu. They also suggested that "where a water contains little that is objectionable besides the inorganic sediment," such as might well be concluded about Waikolu, "a degree of purification can often be obtained with mere sedimentation which will render the water fairly acceptable."[30]

The extent to which plain sedimentation removed particulate matter from water depended on the size and shape of the particles, the length of time in which they were permitted to settle, the shape and depth of the settling tank or basin, and stream flow. Generally, the finer the sediment, the slower the water must be for it to settle. The speed of the water in the sedimentation chamber

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[29]F.E. Turneaure and H.L. Russell, *Public Water-Supplies* (NY: John Wiley & Sons, 1910), p. 534; Steel, *Water*, pp. 316-317. Estimates of removal of odors and tastes by aeration range as high as 75%. Earle Lytton Waterman, *Elements of Water Supply Engineering* (NY: John Wiley & Sons, Inc, 1938), p. 234.

[30]Turneaure and Russel, *Public Water-Supplies*, p. 425-426.

and settling time were determined by the chamber's configuration.[31] The sizes of particles at Waikolu are unknown, as is the formula used to determine the configuration of the sedimentation tank.[32] The tank was sloped to impart a fall of 6" over the elongated path created by the baffles. A combination of pipe size reduction, screens, baffles, a weir and overflows were important features utilized in the sedimentation chamber at Waikolu to reduce stream flow. After leaving the intake dam, water flowed into and out of the aerator and into the top of the sedimentation tank through 15" "Hume" concrete pipe. A screen of 1/4" copper mesh blocked large debris at the entry point to the tank, and another screen of 1/8" copper mesh at the chamber exit insured no large pieces passed into the narrower, 8" pipe. Two longitudinal baffles slowed the current by directing the water around five 90 degree angles, and stretched the settlement distance from 17'-0" to approximately 45'.[33] After the fifth turn, water flowed over a 4" x 1/4" x 2'-8" "sharp crested brass weir" and passed through the second screen before exiting through a 12" to 8" pipe reducer. By itself, the reduction in total pipe diameter from 15" to 8" restricted flow by almost one-half. The tank was fitted with two overflow slots, one rectangular measuring 2'-6" x 3" just inside the water entrance and 3" below the redwood plank top, and one trapezoidal opposite the weir and 6" from the top. Cleanout was manual, either through valved drains located beneath the weir and at the base of the tank below the exit pipe, or through manual removal of the tank top and shoveling or scooping out the sediment.

Repairs to other parts of the existing pipeline completed the 1937-1938 overhaul. On its way to the settlement, the line crossed the Waikolu stream twice, as well as the Waialaea valley and another, smaller ravine. Connections differed at the various crossings. In the Waikolu valley, engineering plans called for 6'-0" lengths of 8" concrete "Hume" pipe cradled in channel iron riveted to an I-beam resting on two rough rubble masonry piers. Spanning a total of 20'-0", the

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[31]The following description of the sedimentation tank is taken from the drawing entitled "Structural Details" prepared for the "Extension of 8-inch Water Line and Improvement of Waikolu Intake," 1937, sheet 3 of 4.

[32]"When the suspended impurities normally present are of such a nature that 50 percent are settleable (of a size and weight such that they will subside in a period of 24 hours or less under comparatively quiescent conditions) it will be advisable to consider the possibilities of providing for natural subsidence." Waterman, *Elements*, p. 206. In the early twentieth century, twenty-four hours was considered the minimum amount of time for adequate sediment deposit to occur. Turneaure and Russell, *Public Water-Supplies*, p. 427.

[33]Engineers recognized the difficulty in designing baffles that reduced water speed without creating currents within the chamber that counteracted sedimentation. Hardenbergh, *Water Supply*, p. 345.

pipe was to be strapped to the channel and grouted with cement.[34] As constructed, the pipe was encased in a concrete jacket. At the site of the former USLIS, the crossing was constructed of a self-supporting, flanged section of 8" cast-iron pipe, a departure from other cast-iron pipe used in the system at this time that had no flanges but was either butted and sleeved at joints, or was of the standard hub and spigot variety packed at the joints with cloth and lead. Between the Waialaea stream and USLIS ravine crossings, the system branched to supply the USLIS through a 4" pipe and the Kalaupapa settlement through a 6" pipe. This junction was modified to provide a centralized reduction point, and a new clean out branch and valve installed.[35]

The Final Extension

The newly reconstructed Waikolu intake offered significant advantages over the previous wood flume arrangement, but did little to ameliorate its constant clogging. Indeed, by 1946 the Superintendent questioned the benefits derived from such repairs: "There seems to be little or no improvement over the former situation," he noted, and requested the Public Works Department modifications recently put in place be inspected and evaluated. Severe weather in the early 1940s highlighted remaining weaknesses in the intake and pipe system. "Exceptionally heavy rains" filled the diversion ditch with landslide debris such as boulders, soil, trees and grass that reached the top of the dam and could take the better part of a week to clean out. (The ditch was one of several remaining from the era of taro cultivation.) Lamented the Superintendent in 1943: "continuous storms...filled it in as fast as we could clean it out. We see no possible way to keep it clean." Two years later, he reaffirmed that prognosis, noting that "We have been forced into Waikolu again to clear the dam at our Waikolu system head. Almost every rain storm that comes in Waikolu fills our intake with stone, dirt and trees from the mountain side." Evidently, a large quantity of silt had built up near the top of the mountain and washed down into the intake with every rainfall. He reported similar problems at Notley, "all cleaning...is handwork of the hardest kind, all soil must be shoveled out by hand." Edwin Lelepali recalls vividly the difficulty of cleaning out Notley, work he performed regularly in the 1960s and 1970s.[36]

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[34]Engineering drawing, August, 1937, sheet 4 of 4. Existing crossings differ from those depicted in these drawings.

[35]Board of Hospitals and Settlement, *Annual Report*, 1938, p. 31.

[36]Board of Health, *Monthly Report*, March, 1942; December, 1943; March, 1944; March, 1945; September, 1945; December, 1945; November, 1945. Interview by Sharon Brown, NPS Historian at Kalaupapa National Historic Site, with Edwin Lelepali and Joseph Mollena, Kalaupapa, Hawaii, December 14, 1998.

In 1948, the Waikolu system was extended for the last time, the head reaching the point at which it can be seen today (1998), approximately five miles from Kalaupapa, at about 560' elevation. Unlike previous intakes, the new arrangement drew water from the main Waikolu stream. A new impounding reservoir, formed by a concrete dam approximately 3' wide and 15' long, extended across the stream. Water backed up to form a large holding pool that facilitated preliminary sedimentation. A metal grate across the top of the dam on the east side screened out logs and large debris as water passed through and into two 8" pipes that connected to the system at the old head. The dam also has a control gate to divert water from the pool for intake maintenance.

Flumes nonetheless remained components of the Waikolu system until it was abandoned with the construction of the well system in the early 1980s. Joseph Mollena and Edwin Lelepali recall cleaning out the flume segments in the 1960s and 1970s. During the winter season, heavy rains carried leaves and debris down the *pali* and into the system. The narrow flumes became severely restricted and crews were sent to clean them out, a procedure that required removing the wood covers and shoveling out the sediment. It is symbolic of how slowly change occurred at Kalaupapa that Mollena and Lelepali performed the same flume cleanout procedures in the 1970s that superintendents a half century earlier had reported.[37]

Indeed, maintenance on the Waikolu system during its final decades resembled in many ways the arrangements of the early part of the century. Patient Edwin Lelepali worked under the Temporary Release (TR) program to monitor, maintain and repair the line. Earning $1.30 per hour, he and other residents worked with state workers like Joseph Mollena, shoveling sediment from storage reservoirs, inspecting the line, building diversionary dams up the valley, and repairing pipeline. When working up the valley, they ate and slept at a crew house located about halfway to the system head. Mr. Lelepali spent seven or eight years working on the system, first as a laborer, then as the first of the crew to inspect the line and close the shutoff valve for repairs; his experience led to his promotion to supervisor. The work was often unpleasant: much of the routine maintenance took place during the cold rainy season, and dam construction required swimming in the cold stream to move and place rocks. Discomfort from cold and dampness was acute, and workers to this day attribute joint ailments to work in the cold, damp conditions of Waikolu.[38]

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[37]Interview by Sharon Brown, NPS Historian at Kalaupapa National Historic Site, with Edwin Lelepali and Joseph Mollena, Kalaupapa, Hawaii, December 14, 1998.

[38]Interview by Sharon Brown, NPS Historian at Kalaupapa National Historic Site, with Edwin Lele and Joseph Mollena, Kalaupapa, Hawaii, December 14, 1998.

Epilogue

By December, 1980, when Kalaupapa became a National Historical Park, the water system had deteriorated considerably. The Hawaii Department of Health, which still owned and operated Kalaupapa as a treatment center for patients with Hansen's disease, was concerned about a polluted water supply. Under legislation establishing the park, the National Park Service was charged by Congress "to provide a well-maintained community," and the reconstruction of the water system was undertaken in fulfillment of that directive. A preliminary survey of the system noted it was "subject to recurrent breakage due to its location, and (was) extremely maintenance-intensive." In the lower part of the distribution system, concrete water storage tanks and pipelines leaked, and a later reconnaissance trip by the Denver Service Center, in 1983, indicated that "much of the distribution system is in poor condition," including fire-fighting standpipes. Tanks leaked over 60,000 gallons per day, about 60% of average daily demand (although some water was lost through shutoff valves). Cast-iron water mains throughout the settlement were generally sound, if somewhat tuberculated (a buildup of residual minerals from the water), but lead-packed joints leaked and the subsystem supplying water to buildings was "found to be somewhat worse structurally."[39]

Working with the Hawaii Department of Health, the National Park Service began reconstruction of the Kalaupapa water system. Considerations of both topography and availability influenced the siting of the new well. Based on electrical resistivity soundings and on the difficulty of site access at Waialeia valley, Waihanu valley was selected, although depth-to-water was undetermined at selection, and was likely deeper than would have been the case at Waialeia. When drilling was completed in August, 1983, Phase I provided "a well pump with required power and controls, and a transmission line to carry water from the new well to the existing storage tanks." Upon completion of Phase I, the existing 6" transmission line immediately east of Kalawao, that transported water from Waikolu valley to the peninsula, was cut and plugged, although the length between Kalawao and the storage tanks remained in service "to serve the comfort station, fountain, and hose bibs at Kalawao." A contract for a second well was awarded in December 1983. Following that, reconnaissance for Phase II examined "the remainder of the existing system to determine the rehabilitation effort necessary to upgrade the system and the time frame for this work." Under that phase, work was planned for September through

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[39]Chief, Division of Water Resources, Western Region to Regional Director, Western Region, "Field Trip Report," October 1, 1982, p. 2; Pat Fleming and Terry Goodrich to Assistant Manager, Alaska/Pacific Northwest/Western Team, Denver Service Center, "Trip Report," June 15-21, 1983; Task Directive, Kalaupapa National Historic Park, Package 107, "Reconstruct Water System: Phase I," 15 April 1983, p. 1.

December, 1985.[40]

Conclusion

Obtaining potable water was an important issue from the founding of the settlements at Kalawao and Kalaupapa until the national park was established in 1980 and the National Park Service installed a new system. Inadequate and undependable supplies in nearby valleys led to the development of the pipeline delivery system from the verdant Waikolu valley over a mile from the peninsula's easternmost point. The system was replete with contradictions: the same rainfall patterns that made it an abundant, year-round source of potable water, also brought rock slides and debris that shattered and clogged the system throughout the four-month rainy season. In a continual quest to assure a cleaner and more regular supply, wood flumes replaced drainage ditches; concrete and cast iron pipe replaced wood flumes; and the system was extended up the Waikolu valley, eventually stretching 3.5 miles to the head. Nonetheless, the system was still vulnerable to the vicissitudes of weather-induced rock slides and debris accumulations. It is only when it became a National Park Service area and had stopped accepting new patients a decade-and-a-half earlier, that the supply of potable drinking water became readily available and reliable.

[40]Charles Hunt to the Record, Memorandum, "Electrical Resistivity Soundings on Kalaupapa Peninsula, Molokai," 16 June 1982; Task Directive, 15 April 1983, p. 2; Pat Fleming, Environmental Engineer, and Terry Goodrich, Park Planner, Alaska/Pacific Northwest/Western Team, Denver Service Center, to Assistant Manager, Alaska/Pacific Northwest/Western Team, Denver Service Center, "Trip Report," 15-25 June, 1983, pp. 2-3; Chief, Division of Water Resources, Western Region to Regional Director, Western Region, Memorandum, "Field Trip to Kalaupapa regarding location of potable water sources, Molokai, Hawaii," 30 July - 10 August, 1982.

Appendix A
Number of Patients at Kalawao and Kalaupapa, 1866-1899

Year	Admissions	Deaths	Discharged	Remaining
1866	141	36		115
1867	91	24	12	170
1868	131	27	7	267
1869	190	59	6	392
1870	57	57		392
1871	178	52		518
1872	91	63		546
1873	415	142	9	810
1874	78	141	16	731
1875	178	149	6	754
1876	75	119	6	704
1877	122	129	3	694
1878	209	111		792
1879	92	194	2	688
1880	51	151		589
1881	195	129		654
1882	70	111		613
1883	300	150		763
1884	108	167	2	702
1885	103	142		663
1886	43	101	5	600
1887	220	111	1	708
1888	71	236	12	1033
1889	307	149	3	1187
1890	185	158		1213
1891	141	210	2	1142
1892	105	152		1095
1893	209	151		1153
1894	129	159		1123
1895	105	141		1087
1896	142	114		1115
1897	124	140		1099
1898	75	114	1	1059
1899	61	104	2	1014

Source: Board of Health, *Report*, 1909.

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