A HISTORICAL SUMMARY OF IRRIGATION IN HAWAII

WADSWORTH

For Miss Carey Miller
with sincerest aloha! H. A. Wadsworth

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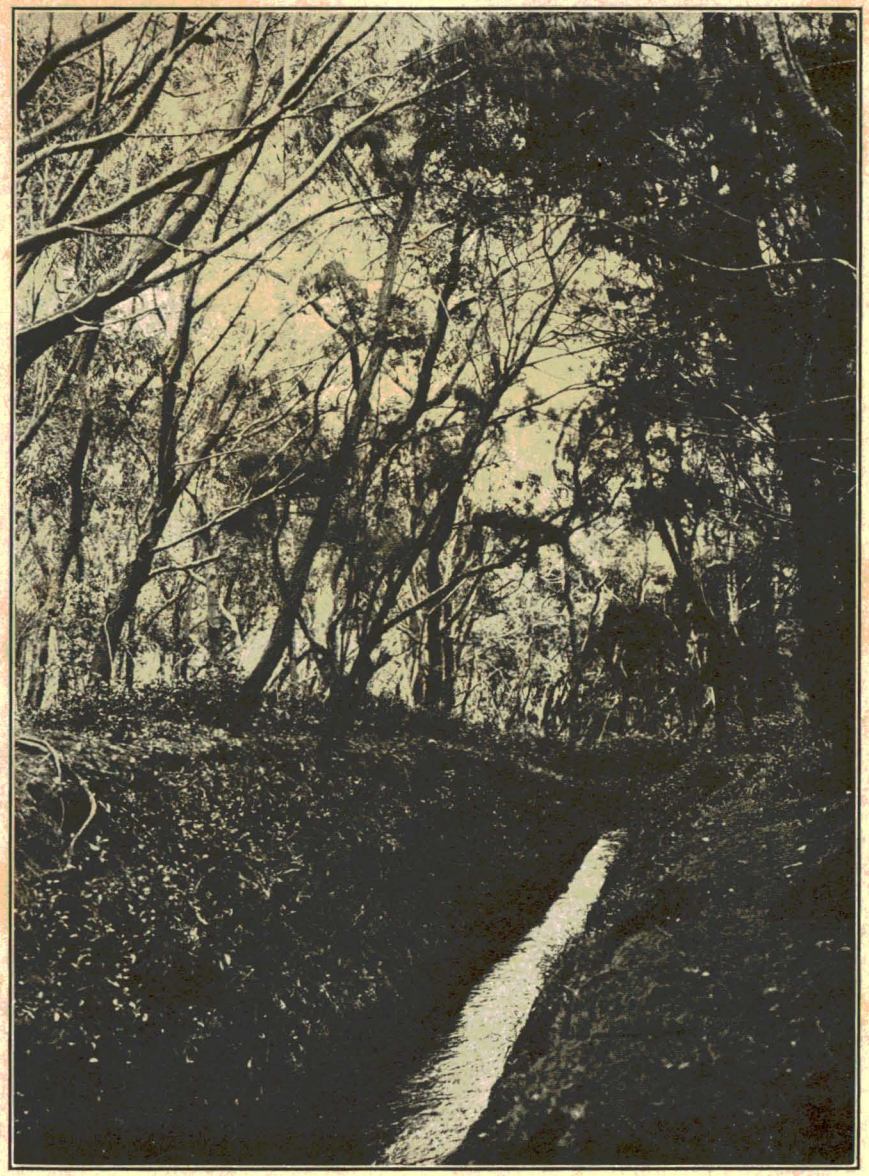

The historical irrigation ditch built by W. H. Rice at Lihue in 1856. At present, considerably enlarged, this ditch, through the German Forest, follows the route of the first irrigation canal for sugar cane in Hawaii. (Original photograph taken about 1885; courtesy of Miss Ethel M. Damon and Mrs. Dora H. Isenberg.)

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In This Issue:

A Historical Summary of Irrigation in Hawaii:

The task of assembling accounts of irrigation development in the Hawaiian Islands, from the prehistoric practices as reported by early explorers and adventurers to such monuments to modern skill and resourcefulness as the Wailoa Ditch on Maui and the Alexander Dam on Kauai, has not been easy. Probably it is not complete. Valuable sources of material in printed form have unquestionably remained undiscovered in spite of diligent search, while many old residents, who, through long association with developments, might contribute materially to the completed whole, have escaped interview.

The accounts of those who lived through the period of most active development have been most valuable. Among these, Mrs. H. P. Baldwin, G. N. Wilcox, Wm. F. Pogue, A. C. Alexander, Judge Antonio Perry and C. A. Buchanan have been most helpful in lifting a story of costs, dates and engineering detail into a position of compelling interest. To each of these, or to their memories, the writer extends his thanks. Acknowledgment is also due to D. H. Baldwin, W. P. Alexander and Professor R. S. Kuykendall for their helpful interest during the preparation of this account. The valuable suggestions of A. C. Alexander, W. H. Taylor and Professor R. S. Kuykendall, who critically read the original manuscript, are incorporated in the present text and gratefully acknowledged.

The preparation of this manuscript does not mark the end of the writer's interest in this study. Additional information with respect to any of the early practices or reference to obscure printed accounts will be equally welcome.

(H. A. Wadsworth.)

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Introduction

Although the practice of irrigation has long been a significant factor in Hawaiian agriculture, a study of the history of its development from a prehistoric practice among the natives to its modern use in sugar production has never been comprehensively undertaken. The story of this transition is not a simple one.

Economic as well as political developments during the period between 1850, which may be taken as the beginning of sugar irrigation, and 1878, which marked the beginning of the modern period of water utilization, had a decided effect upon what might have been a continuous but rather uninteresting development. Sugar prices suffered a severe decline in 1853, probably due, in part at least, to declining interest in the California mines. An unusual drought on Maui in 1862 and the failure of two sugar brokers in 1865 still further depressed the sugar industry.

In addition to these external effects, local developments were important. The Mahele, or land division, of 1848 gave promise of private ownership of land by individuals and companies, as well as suggesting the possibility of leasing the right to divert water from lands in government ownership. Reciprocity with the United States, attained in 1875, was another powerful stimulus to sugar cane development, while annexation in 1898 added further security.

The period of greatest interest in the history of irrigation development is marked by the greatest difficulty to one who hopes to compile a continuous story of development. Early methods with taro or other crops changed little, apparently, between the times of Cook and Vancouver and the Mahele. Plantation records, agency reports and summaries by the Planters' Labor and Supply Company, and later by the Hawaiian Sugar Planters' Association, tend to clarify the development since 1883. Between 1850 and 1883 records are scattered and incomplete. *Thrum's Annual* and the *Transactions of the Royal Hawaiian Agricultural Society* provide valuable material, as do occasional accounts of progress or editorials in the newspapers of that period. The most illuminating sources, however, are the biographies and reminiscences of those who lived through these developments or who, through close association with others active in the early works, acquired a store of anecdotes which often contribute valuable sidelights or unsuspected leads to further inquiry.

The short discussion of the water laws of Hawaii is not intended to be a statement of the modern water code of the Territory with all its ramifications. Its purpose is again historical and attempts to give the barest possible outline of the original but remarkably effective code of Hawaii.

Prehistoric Agriculture and Irrigation

That irrigation had an important place in early Hawaiian life cannot be doubted. Captain Cook (6) in his account of his first landing on Kauai, in 1778, mentions taro plantations at Waimea, saying that "the greatest part of the ground was quite flat, with ditches full of water intersecting different parts, and roads that seemed artificially raised to some height." And again, "The vale ground has already been mentioned as one continuous plantation of taro and a few other things, which have all the appearance of being well attended to." Vancouver (22) also mentions the thrifty growth of taro resulting from artificial watering.

Moreover, certain ancient Hawaiian words add evidence to the assumption that irrigation was significant, if not vital, to native life. The word "wai" meant water, while "waiwai" meant goods or wealth, leaving the suggestion, at least, that an abundance of water was associated with prosperity. Furthermore, the more common word for law or regulation was "kanawai," again suggesting that early laws dealt primarily with water distribution. It is interesting to note that a literal translation of the Old Testament in early Hawaiian would list the ten water-laws of Moses in place of the familiar Ten Commandments.

It is singular, however, that such an important aspect of native life should not find expression in the voluminous folklore and legends of the people. The *Fornander Collection of Hawaiian Antiquities and Folklore* mentions irrigation as pertinent to taro production, it is true, but such reference is secondary to the details of the usual supplications to Kane, the god of water, during the growth of the taro. Apparently the folklore of the people was devoted to the exploits of their gods and heroes and not to the commonplaces of daily life. Even David Malo (10), the source for most knowledge of early Hawaiian customs, dismisses the subject of irrigation with scant notice.

A more comprehensive account of early taro culture is to be found in Campbell's (4) account of his experiences on Oahu in 1809. Campbell emphasizes the labor entailed in the production of this crop. He describes the patches as being something less than one hundred feet square and surrounded by embankments generally about six feet high, the tops of these embankments being planted to sugar cane. Water was admitted to these patches and carried from them by carefully constructed aqueducts and drains, which, according to Campbell, required great labor and ingenuity. Another point of interest in this early account is the great depth of water used in submergence, Campbell giving from twelve to eighteen inches for this figure. The importance of puddling the soil before flooding is also noted, this being done by treading it underfoot until it was close enough to contain water.

It has been suggested that new taro beds were subject to a religious ceremony before use, this ceremony consisting, among other things, of a dance upon the wet floor of the newly leveled patch. The practical benefits of this part of the performance are evident, although no verification of this statement has been possible. Campbell's observations were later substantiated by Corney (5) in 1819 and by Stewart (18) a few years later.

Early Ditches

Although these several authorities and others mention the necessity of irrigation water for taro production, none of the earlier writers mentions the method of ditch

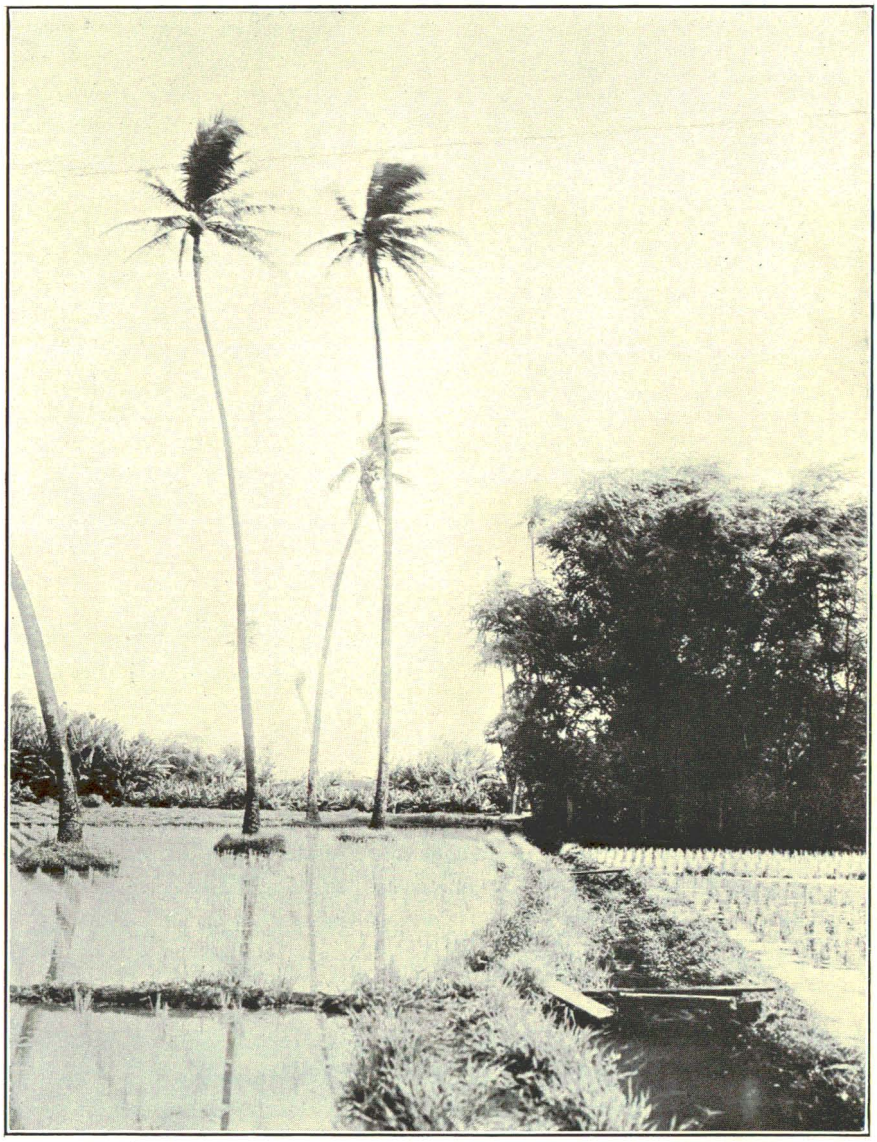

Fig. 1. Rice field at Waikiki, Oahu. Early taro patches were easily converted into rice fields with the increase of the Oriental population. (Photograph from the Bishop Museum.)

construction in any detail. Probably most of them were short and of small capacity, although some must have been more ambitious in view of Campbell's remark upon the labor involved. In any event, it seems clear that the intake structures were usually temporary, being carried away during high water and replaced when needed. As a result, few remains of veritable ancient canals exist and these only if continued maintenance work has been done. The palm-lined auwai in Fig. 4 is not ancient but may illustrate the usual appearance of early ditches. In some cases old canals have been incorporated in plantation distribution systems, but in such cases enlargements and betterments have robbed the old ditch of any evidences of peculiar construction which it may have had. Erosion and weed growth quickly obliterate a ditch if thrown out of use.

Consequently any remains of an ancient ditch attract considerable attention. One of these, on Kauai, takes water from the Waimea River and delivers it to the taro beds near the town of Waimea. Water from this ditch probably contributed to the plantings which Captain Cook reported on the day of his first landing. Native legend, however, carries the history of this stream back to the days of the Menehunes. These creatures, somewhat analogous to the Brownies of other folklore, seem to have had a remarkable capacity for work provided that they might work only at night and leave unfinished any endeavor which could not be completed before sunrise. The construction of the Waimea "auwai," or ditch, is often attributed to these Menehunes, part of the evidence being the peculiarly keyed stones which line some of the lower reaches of the canal. Such stonework is unknown elsewhere in the islands. Apparently this stone lining is the only remnant of an ancient and forgotten civilization. Details of this work are shown in Figs. 2 and 3. The suggestion that the stone lining was the work of a Russian military detachment which occupied a small fort near the mouth of the Waimea River (1817) does not seem to be in keeping with the fact that this ditch was described by adventurers as early as 1798. The site of the stonework is now marked by a bronze plaque giving part of the legend of the Menehunes' activity.

Another bit of construction which gains considerable interest, due to the labor involved and not to age, is a tunnel driven through 200 feet of lava near Niulii, on Hawaii. Here the drilling was accomplished from vertical shafts 10 feet apart and driven to proper line and grade. Williams (24), who describes the tunnel with its stone-faced diverting dam in *Thrum's Annual* (1919), sets the date of construction as between 1823-1849. Since steel stools and blasting powder may have been available at this time, the construction need not have been extremely difficult. Many observers, however, date the tunnel much earlier than the time of the arrival of travelers and adventurers who might have supplied such aids to construction. It is often said that the tunnel must have been drilled by the use of fires built in the headings until the rock was heated, and then quickly doused with water. In such an event the patience and engineering resourcefulness of the workmen must have been considerable.

Still another auwai, much more recent than either of those noted above, could be traced in Nuuanu Valley, on Oahu, until improvements in that part of Honolulu essentially obliterated it.

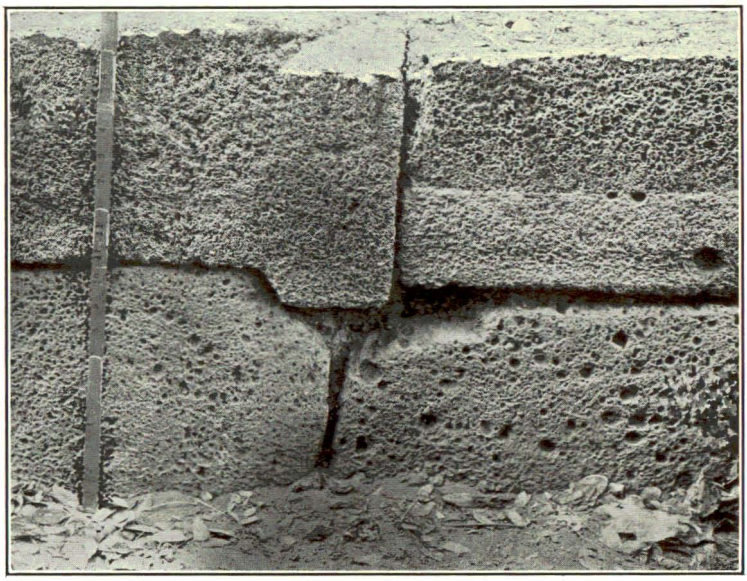

Fig. 2. Stone lining of the so-called "Menehune Ditch," Waimea, Kauai. The faced stone of this lining is found only in this ditch. (Photograph from the Bishop Museum.)

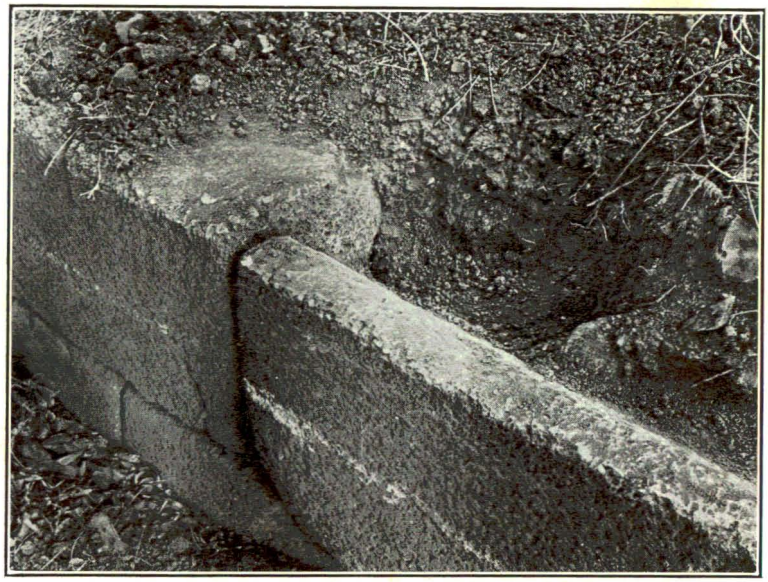

Fig. 3. Another view of the lining of the "Menehune Ditch." Some archeologists consider this stonework a relic of a prehistoric civilization on Kauai; others believe that Russians from a fort at the mouth of the Waimea River in about 1817 were responsible for its construction. (Photograph from the Bishop Museum.)

Irrigation Organization

No account of the simple, although strangely effective, irrigation organization of early Hawaiian people is comprehensive without a basic understanding of the political organization of the time. The conquest of Kamehameha I late in the eighteenth century unified the several independent island kingdoms into a single monarchy of which Kamehameha I was king. Local government was afforded by chiefs, appointed by the king, and holding tenure only by his pleasure. The larger areas controlled by individual chiefs were called "ahupuaas," and although the boundaries of the ahupuaas may have been loosely described, the holding of each chief supposedly carried fishing rights on the sea, taro land on the coastal plains or in the valleys, and forest land in the mountains. This distribution was sometimes accomplished by defining each ahupuaa as an area running from the main divide on the island to the sea and bounded by significant and continuous radial ridges on either side. The water resources of such an ahupuaa would, of course, be sharply defined. Complications were introduced when topography made these ideal boundaries impossible. In some cases streams rising in the domain of one chief would cross his boundary and enter the drainage system of his neighbor. Although such conditions may not have materially complicated native problems of distribution, they have added difficulties to modern interpretation of ancient rights.

Distribution of water within the ahupuaa as well as the granting of homesites and taro patches, called "kuleanas," to commoners, lay in the hands of the chief. Such grants might be withdrawn by the chief and a tenant ejected at the pleasure of the chief, much as the chief himself might be removed at the pleasure of the king. The system was remarkably parallel to the feudal system in Europe.

In spite of the depressing effect that such a system is supposed to have upon initiative, a simple, although a remarkably effective, type of irrigation development was developed. Mrs. Emma M. Nakuina (12) who for many years was an authority on the Hawaiian water code, describes the construction and operation of native ditches in *Thrum's Annual* (1894).

According to Mrs. Nakuina, auwais were constructed at the instigation of the chief of the ahupuaa, the actual construction, of course, being done by commoners. Whether this labor was secured through duress or by promise of participation in benefits is not clear. Sometimes a single auwai served lands in two or more ahupuaas, and in such cases water was distributed to these larger areas in accordance with the number of men provided for construction.

In any event the site of the simple diversion dams seems to have been marked before construction started, and yet Mrs. Nakuina definitely states that construction began at the area to be irrigated and continued up the proposed ditch grade. How an adequate grade might be maintained and at the same time allow the ditch to intercept the stream at a predetermined point without the use of instruments is an interesting speculation. It has been said that a tool, in the form of a long bamboo pole with the nodal tissue removed, was used for this purpose, since water poured into the upper end escaped at the proper rate when the slope was correct. If such a tool were used, it seems clear that the route must have been completely surveyed by this simple means before construction began. The construction of the dam itself and the turning of water into the newly constructed auwai was cause for cele-

bration of religious significance. The desirability of this celebration apparently mitigated against the more simple scheme of building a small dam first and digging downstream ahead of the water on a grade as flat as possible in view of the desired flow and the required point of use. That this more simple scheme was extensively used, despite Mrs. Nakuina's statement, is supported by early observations of G. N. Wilcox, who noted remnants of old ditches near Kilauea, on Kauai, which had patently been dug ahead of a small stream already diverted by a temporary dam. In at least one case this method of construction carried the ditch line into such heavy excavation that the location had to be abandoned and a new route undertaken.

Although the dams were temporary, they were under rather strict control. Apparently no dam was supposed to divert more than half the stream flow, under penalty of destruction by water users below. But if properly constructed a dam became secure from malicious tampering. The penalty for wilfully breaking a dam was death, the culprit's body being used in the necessary repairs as a warning to others. For this punishment there was no reprisal unless, as Mrs. Nakuina naively explains, the culprit was of consequence. In such a case civil war might ensue.

Although the chief of the ahupuaa was master of all the auwais within it, details of administration were delegated to an appointee of the chief, the konohiki. His duties were varied and important. In cases of a cooperative venture between

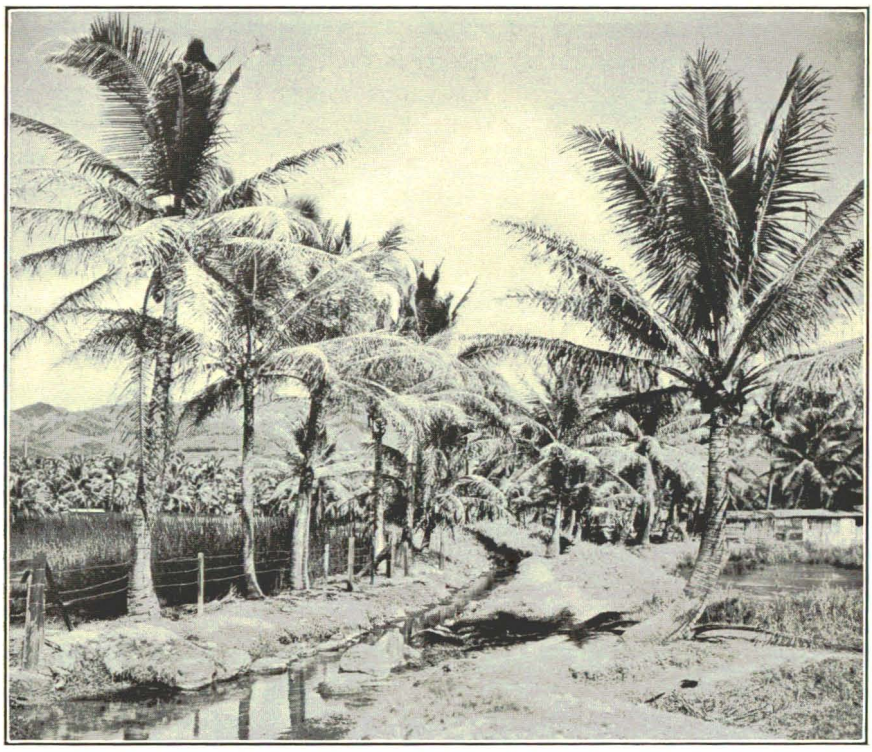

Fig. 4. An early auwai in Honolulu. This ditch on the Ward place was probably supplied by a spring near King street. (Photograph from the Bishop Museum.)

neighboring ahupuaas, the konohiki of the major area became water master of the canal and divided the water between the two areas in proportion to the number of men furnished. Details of the method of division are not clear in Mrs. Nakuina's account. Apparently distribution was on the basis of time of flow, since no method of measurement is recorded. Moreover, the konohiki was responsible for internal distribution to the taro patches themselves as well as for the maintenance of the system. Users of water from an auwai were subject to call by the konohiki for maintenance work, the penalty for failure to comply being a withholding of water from the taro of the delinquent. The rapid deterioration of the kuleana in such a case might readily lead to eviction by the chief.

Distribution of water to the lands of the kuleana holders was usually on the basis of time, small areas using almost the entire flow of the auwai for a few hours, while larger tracts carried rights for several days. Apparently time was measured by the position of the sun during the day and the stars at night.

Although Mrs. Nakuina makes no mention of other methods of distribution than that noted above, Judge Perry (14) suggests that others were used to some extent. Possibly these alternative methods were in early use and gave place to the more common distribution, as described by Mrs. Nakuina, when the demand for water, due to increased cultivation, required a more conservative practice. One of these alternative methods involved the delivery of the entire stream to a large tract during daylight hours, while night water was supplied to a neighboring tract of equal size. When all small taro patches within the larger areas had been served, the procedure was reversed and the delivery continued. Under other conditions, presumably those of abundant water supply and limited demand, the upper patch received as much water as needed without regard to time. When the operator of this patch was satisfied the next lower was served in a similar manner until all areas along the auwai had been supplied. The procedure was then repeated. Judge Perry also notes cases in which some patches were supplied by overflow and seepage from higher lands and not directly from any watercourse. In any case the distribution seems to have been based upon the idea of rotation and not continuous delivery, although a continuous flow seems to be ordinarily used for taro irrigation in modern practice.

Several of the conditions of the ancient code form interesting parallels to the best features of water law as developed in western United States. Beneficial use of water in the hands of the commoners was essential to continued delivery under the early Hawaiian code as it is among western states operating under the doctrine of appropriation. Compulsory maintenance work on the auwais under the direction of the konohiki, with the threat of refusing delivery, with possible dispossession, is at least analogous to maintenance assessments or water tolls in modern irrigation development, while the powers of the konohiki in rationing water during periods of scarcity are parallel to those of water masters on some important streams in western America. Furthermore, the delivery of water upon the basis of labor contributed in the construction of the auwai is suggestive of the distribution of modern costs upon the basis of benefits received, a method frequently used in drainage ventures. From the nature of the political background and the consequent lack of land titles, no idea of riparian rights needed consideration.

It is evident that the simple water code outlined above might and probably did work unjustly upon commoners out of favor with the chief and his konohiki. In fact a law aimed toward the correction of some of the abuses of the old system is published in the *Laws of 1842*.

In translation this interesting law is worded as follows:

> In all places which are watered by irrigation those farms which have not formerly had a division of water shall, when this new regulation respecting lands is circulated, be supplied in accordance with this law, the design of which is to correct in full all those abuses which men have introduced. All those farms which were formerly denied a division of the water, shall receive their equal proportion. Those bounties which God has provided for the several places should be equally distributed in order that there may be an equal division of happiness among all those who labor in those places. The allowance of water shall be in proportion to the amount of taxes paid by the several lands. . . . . That the land agents and that lazy class of persons who live about us should be enriched by the impoverishment of the lower classes, who with patience toil under their burdens and in the heat of the sun, is not in accordance with the designs of this law.

Since water in Hawaiian streams was usually sufficient for the irrigation of valley and flood-plain lands in taro, even at low-river stage, the surplus waters find scant notice in the early water code. The heavy construction required for the utilization of these waters upon near-by slopes was beyond the engineering resources of the time, resourceful as the natives may have been. Apparently such water was allowed to follow its natural course to the sea. Patently this water belonged to the chief, at the pleasure of the king, and in all logic the legal ownership passed to the chief along with the ownership of land upon his completion of the legal requirements of the Mahele. The adjudication of these rights, commonly called the "konohiki rights," during and after the Mahele, forms one of the most interesting chapters of modern Hawaiian water law.

Early Taro Culture

Although all early travelers note the culture of sugar cane, yams and bananas in addition to taro, it seems clear that taro alone was irrigated, except that other plants established along the edges of the patches or on the banks between them might benefit by seepage water. As has been indicated, some early accounts emphasize the great height of the banks and note that some were wide enough to allow for a road or rows of banana plants on their tops.

Such descriptions of taro production are apparently incomplete and emphasize a method of culture which was not common except in particular areas. Two methods must have been in general use. One practice was employed when spring water under significant pressure head was available, while the other, involving low levees and shallow depths of submergence, was used with the more common stream diversions. Both Campbell (4) and Corney (5), who describe the high banks and great depth of water in taro production, had most of their agricultural experience near Pearl Harbor, on Oahu, where natural springs were numerous.

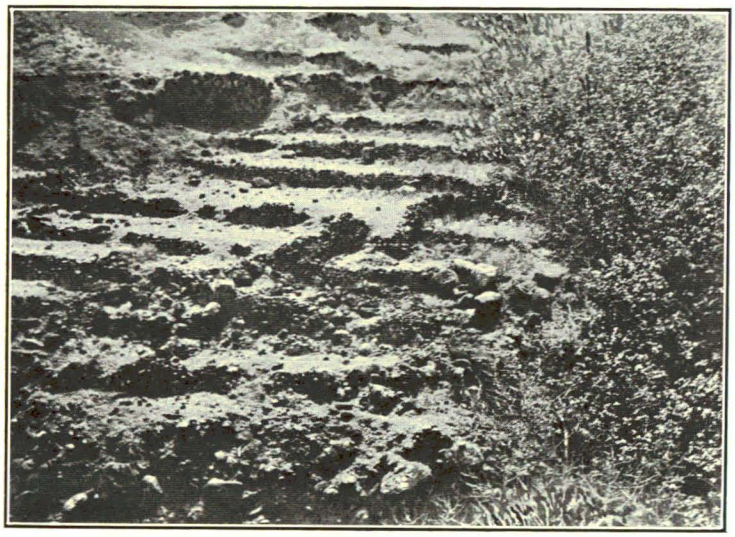

Fig. 5. Remains of taro patches, Awaapui Valley, Kauai. The black wall in the background is the face of an ancient heiau. It is fifteen feet high. (Photograph from the Bishop Museum.)

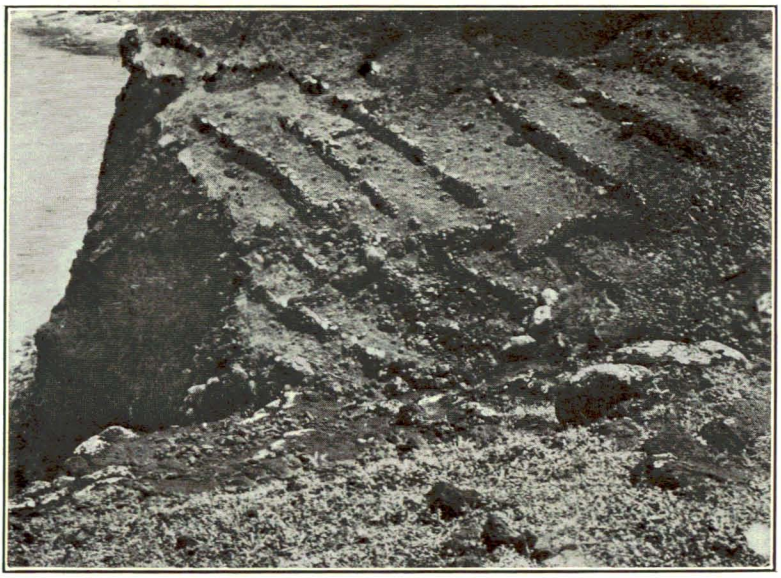

Fig. 6. Another view of the taro beds in Awaapui Valley, Kauai. These patches on the cliff over the sea were in unusually difficult topography. (Photograph from the Bishop Museum.)

Professor John Wise, of the University of Hawaii, is authority for the statement that natural spring waters were utilized by surrounding the spring with high, water-tight levees, which enclosed about half an acre of ground. Piles of dirt thrown up inside these basins provided planting area for the crops to be grown. Bananas planted on the tops of the piles secured adequate moisture without submergence while sugar cane and yams planted at lower elevations and, of course, nearer the water level, supposedly secured moisture in accordance with their needs. Taro planted still lower on the slopes was partially submerged. This method of culture was necessarily limited to areas in which natural springs occurred under such conditions that a two- or three-foot head might be maintained.

Flat culture was much more common. When this method was used low levees were thrown around conveniently shaped areas of land and water admitted from the neighboring auwai. Apparently water was admitted to each basin from the one above it, if not from the auwai itself, drainage from the last patch finding its way into the original stream or another ditch.

Few remains of the high banks, necessitated by the common practice when springs were used, exist at present. In most ancient taro beds the levees are less than three feet high and relatively narrow. Perhaps the best unspoiled taro patches at present are to be found in the Kalalau Valley, on Kauai. This valley, although it once supported a large community, is small and until recently has been inaccessible except by sea. Landing from boats is often hazardous. Consequently, no modern use, except for cattle grazing, has been made of it. The old taro banks found here are much smaller than those reported by Campbell (4) and Corney (5). In no instance were banks more than three feet high discovered, except in cases where the topography demanded distinct terracing. Nor were the tops of the banks of significant width. Only the stonework in the old levees remains, the earthen facing, as described by early travelers and required in view of the construction, having disappeared. The remains of ancient taro patches in Awaapui Valley on the Napali Coast of Kauai are shown in Figs. 5 and 6. Fig. 7 shows similar evidences in Makahua Valley, Oahu.

Some authors refer to the taro patches as beds which are excavated to a depth of two or three feet in place of enclosing small areas by banks built upon the normal ground surface.

"Haole" (8) describes early taro production somewhere near Kaneohe, on Oahu. Here the bed method was used, their newly leveled bottoms having been beaten with coconut stems to aid in holding water. As in present times, planting material came from suckers from one year's growth or from tops of harvested taro.

"Haole" seemed impressed with the intensity of production at Kaneohe, saying that "forty square feet of land planted with kalo will afford subsistence for one person for a whole year." The author probably means an area forty feet square, since this interpretation justifies his additional statement that "one square mile planted with the same vegetable will feed fifteen thousand one hundrd and fifty-one persons for the same length of time." In his computation he allows considerable area for paths and ditches.

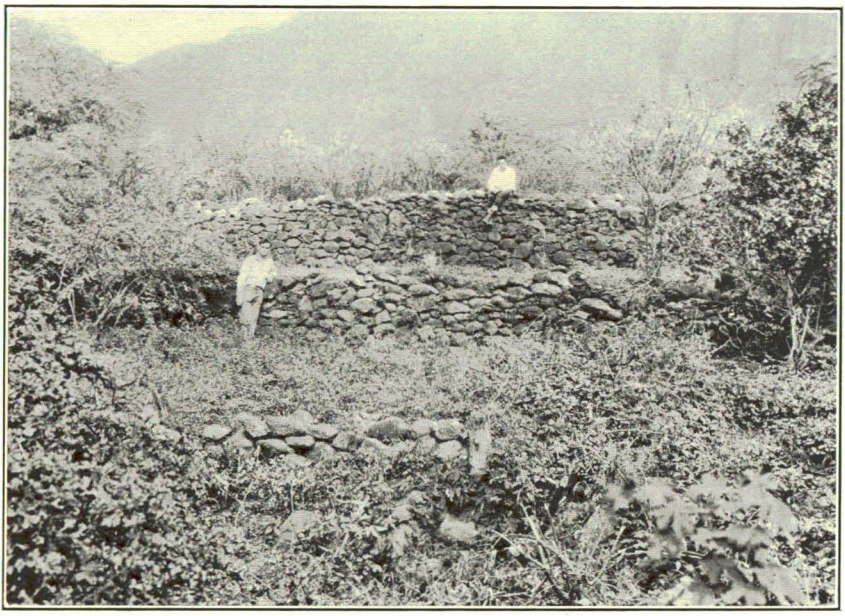

Fig. 7. Taro patches in Makahua Valley, Oahu. The height of the terrace faces may be judged by the figures. (Photograph from the Bishop Museum.)

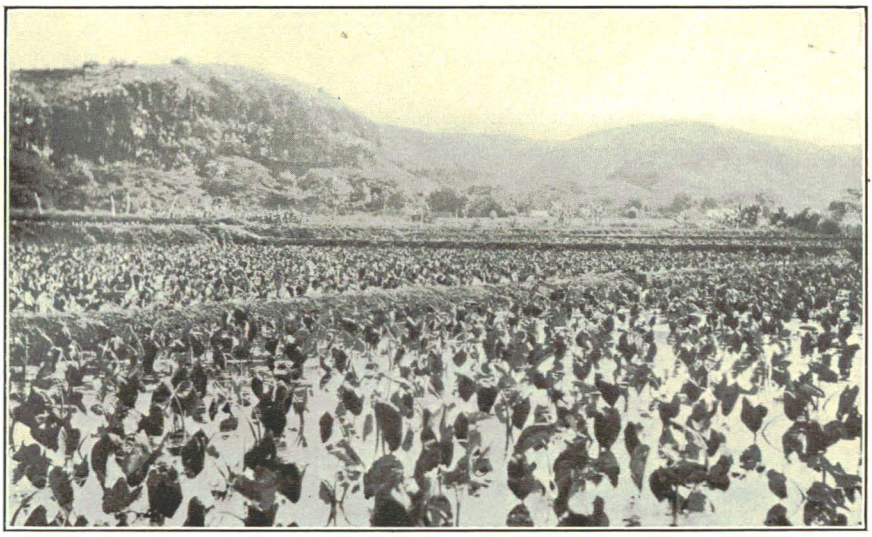

Fig. 8. Taro beds. Although this photograph is recent, it represents an ancient practice. (Photograph by K. B. Tester.)

Campbell's (4) mention of the actual production of the crop concerns the labor involved and not the value of the product. "This mode of culture," he said, "is particularly laborious and in all operations those engaged are almost constantly up to the middle in mud. Notwithstanding this, I have often seen the king working in a taro patch." Such a statement must have been based upon observations on the type of culture used with natural springs.

Taro production in the early days was a continuous operation, harvesting and replanting being determined primarily by rate of consumption by the kuleana holder and his dependents. Supplies of mature tubers were removed from the beds as needed and carried away from the growing area for cleaning and preparation as poi. Replacements of planting material in the beds provided for a continuous supply.

Whether the modern pathological trouble of taro root-rot was a significant factor in early production seems doubtful. Some authorities believe that the causative organism is some variety of the nematode Tylenchus, which also seems to have played a part in the so-called failure of the Lahaina variety of sugar cane. Whether there is any connection between the rapid spread of Lahaina cane in later years and the present menace of taro root-rot, in view of the similarity of the organisms involved, is not known. In any event, the early harvesting methods would tend to keep such a soil-organism under control if it were present. Under modern practice, the irrigation supply is usually continuous if possible, one reason given for such a type of delivery being that taro rot is retarded by the abundant use of fresh water. The reason for this control is unknown. As has been stated, the delivery of irrigation water to the ancient patches was usually by rotation.

Early Sugar Culture

The present sugar industry found its beginning in an atmosphere of indefinite land titles, ill-defined water rights, and a native superstition which endowed certain individuals with the powerful agent of tabu. The first two of these obstacles were removed through the action of a wise and generous king, while the power of the tabu, being of local religious origin, naturally declined with the importation of foreign labor. Consequently, the history of the sugar industry may well be divided into two chapters, the first extending to the Great Mahele of King Kamehameha III, by which action the titled ownership of land, and presumably water, by individuals was possible, while the second carries the history from this point to the present.

The earliest travelers to Hawaii note the presence of sugar cane, yet the use of the word "indigenous" in this connection may be subject to criticism. Since the early cane was similar to that found elsewhere, it is possible, if not probable, that planting material was brought to the islands by the early Polynesian settlers, whatever their origin may have been. In any event, the plant was widely distributed at the time of the first written mention. Since it formed a significant part of native food, this wide distribution is not surprising. Willfong (25) is authority for the statement that wild cane was planted in much unused land after the wars of Kamehameha I in order that an abundance of food might be available for travelers.

Apparently such cane was eaten in the stick, the first extraction and partial refining being credited to a Chinese who came for sandalwood in 1802. The simple mill and boiling equipment seems to have been brought from China and used for a short time on the island of Lanai. The apparatus was subsequently disassembled and returned to China, presumably in the same ship that brought it to Hawaii.

This early activity on Lanai seems to be of only historical significance, since no further record of sugar manufacture is noted until 1819, when Francisco de Paula Marin is said to have made sugar in Honolulu. An Italian is credited with sugar manufacture in Honolulu in 1823.

In the meantime there seems to have been some activity on Maui, for in the same year (1823) Antone Catalina and a Chinese, Hungtai, established mills at Waikapu and Wailuku, respectively. It is probable that interest in manufacturing sugar has been essentially continuous in this high-producing area since that date, although this continuity is not demonstrated in the records.

Such early accounts deal entirely with the establishing of crude mills and the preparation of sugar. It is probable that the cane used was native cane growing in the neighborhood and carried to the mill. The first mention of a sugar plantation in the sense that cane was actually planted and cared for with subsequent milling in mind is associated with John Wilkinson, who in 1825 laid out a coffee and sugar plantation in Manoa Valley, on Oahu. Apparently no difficulties were encountered in growing the cane, although operations were severely handicapped by lack of capital and suitable tools. Wilkinson's death, prior to the first cane harvest, curtailed all activity and the plantation soon wasted away for lack of care. Another planting in Manoa, planned for the production of sugar and rum, ceased operation in 1829.

In 1835 a Honolulu firm, Ladd and Company, secured tenancy rights to a tract of land near Koloa, on Kauai, for silk and sugar culture. Although difficulties of operation were great and the original company did not long survive, this venture seems to have been the forerunner of the present system of corporation operation.

No land titles were possible at this early date, as has been indicated, and permission to occupy must have been primarily one of tolerance. Moreover, no tools for sugar production were available, and early accounts tell of plows being drawn by natives, although such statements are sometimes questioned. Labor troubles were also present, not only because it was difficult to interest the easy living natives in the hard work required, but also because of the relics of the declining tabu system which still prevailed. Kahunas or native witch-doctors might, and doubtless did, forbid work on certain days by declaring such effort *tabu*. From such a system the plantation seems to have had little recourse. Crudities in methods, resulting in low recovery of sugar and sugars of inferior quality, were also factors adding to the difficulties of these pioneers. Two mills were established and abandoned at Koloa prior to 1840. A third was built in 1841.

In spite of these handicaps, Ladd and Company demonstrated the possibility of sugar production on a commercial scale. Thrum (21) gives the production for 1838 as 5,039 pounds of sugar and 400 gallons of molasses. The arrival of M. Victor Prevost, an experienced sugar manufacturer, at about this time, soon brought about an improvement in quality of the product from Kauai.

It is natural that the activity of Ladd and Company on Kauai should stimulate interest in other districts. Twenty-two mills were in operation, or soon to be erected, in 1838, although it is clear that such mills could have had little similarity to their modern highly efficient successors. Willfong (25) describes several typical mills on Maui as he observed them in 1849. Those used on the large percentage of the twenty-two locations noted above were probably no more elaborate. According to Willfong, the entire factory consisted of a battery of wooden rollers, perhaps 18 inches in diameter and two feet long, mounted vertically and driven usually by animal power, and a series of three open try-pots bought from visiting whalers. Presumably the cane was fed by hand, the juice being simply concentrated by successive boiling in the open kettles. He makes no mention of the processes leading to crystallization and sugar recovery. In fact, he stresses the profits resulting from the sale of the thick syrup to whalers, presumably for rum-making. The cane trash was usually insufficient fuel for the boiling down, indigo being used as a supplemental supply at Lahaina. The area cleared by this means was subsequently used for the first planting of a supply of seed cane brought by Captain Edwards, of the whaleship George Washington. This cane was subsequently called "Lahaina."

Although it is doubtful that the simple mills described by Willfong and called "screeching nuisances" by President Lee (9) of the Royal Hawaiian Agricultural Society, could have produced the amount of sugar credited to the Ladd and Company plantation in 1839, it is probably true that most of the mills of the period were of about that order. No great capital was invested in machinery, and what machinery was necessary was readily portable and seems to have changed hands rather frequently. Moreover, most mills seem to have depended upon

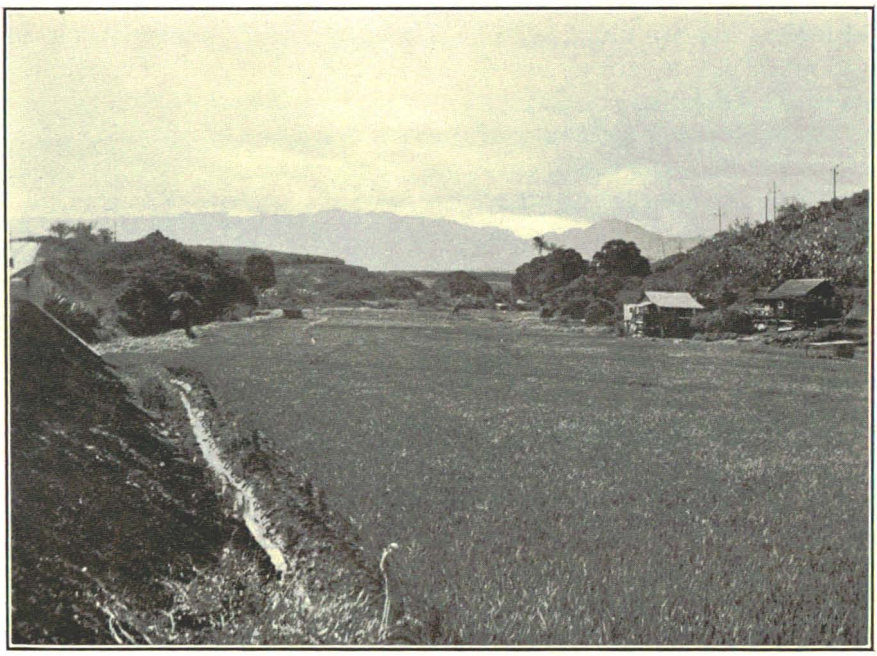

Fig. 9. The Waiawa Valley, Oahu. Although this valley has long been in rice, it is the site of the first venture in the irrigation of pineapples in Hawaii. (Photograph by the author.)

native wild cane—little capital being tied up in a growing crop. References to irrigation in the accounts of the early history of sugar are conspicuously absent. It is highly improbable that any irrigation was done by Ladd and Company, while the cane milled at Lahaina was only incidentally watered, since it was grown only on the banks of the taro patches.

Because of the simplicity of the mills, the low cost of cane production and no investment in irrigation works, the early business of sugar production seems to have been extremely flexible. Mills were established, produced sugar or syrup for a few years, and then were abandoned or moved to a new site if conditions seemed more favorable in the new location.

Another factor making for flexibility in the early days of sugar production lay in the inability of the producers to own land. As has been indicated, ownership to all land lay in the hands of the king, and its uses were permissive only. It is clear that such a condition could not have fostered a progressive and highly specialized agriculture.

The effective transition from essentially feudal conditions, which existed since ancient times, to surety of land titles in individuals within only about ten years, is a splendid commentary upon the wisdom, farsightedness and generosity of King Kamehameha III. The steps leading to this remarkable decree of the king need not be considered here, since the political and social background of the time as well as the simple but effective procedure by which land titles were brought into the hands of individuals is ably discussed by Alexander (1). It seems clear, however, that the necessity of fostering and encouraging the sugar industry was not a vital factor in the movement.

Moreover, it is strange that the efforts of the Land Commission during its short but active life under the authority of the Act of 1846 should have been directed entirely toward confirming claims for land titles. No recognition of the water right previously enjoyed by the land was made either in the text of the act authorizing the commission or in its actions. However, it seems to have been tacitly understood that the granting of title to a particular parcel of land to an individual carried with it the right to the usual amount of water from the usual source. It is hardly surprising that complications should have arisen.

A means of settling these inevitable disputes was provided in 1860 by the appointing of three persons in each election district to act as Commissioners of Private Ways and Water Privileges. In addition to other things, the duties of these commissioners involved determining all controversies respecting rights to water between individuals and between individuals and the government. A right to appeal to the Circuit and Supreme Court was available. In 1888 the commission was reduced to a single member and appeal limited to the Supreme Court only. In 1907 the office of commissioner was abolished and its duties transferred to the circuit judges.

The findings of the commissions and judges and decisions of the courts have developed a code which is simple to understand in its broad principles, entirely operable under the topographic conditions of Hawaii, and still is entirely different from the English conception of riparian rights and the doctrines of appropriation

and beneficial use so widely used in western America. The litigation involved in the development of Hawaii's water resources has been comparatively small.

The metamorphosis of the ancient system of water distribution into a modern workable water code has been sure and methodical. Basic conceptions are, in general, clearly defined either by the original premise that title to necessary water passed to the individual when he received title to land at the time of the Mahele, or by subsequent decisions by the courts.

In general, the present code holds that title to water originated at the time of the Mahele. Commoners at that time secured title to the water required for the continued production of their taro patches, while a minor chief holding an ahupuaa came into titled ownership of all waters rising upon it, less such water as the holders of kuleanas required under the old practice for domestic use and for the cultivation of their taro. Water originating upon government land was subject to the same limitation.

Moreover, it has been uniformly held that water passes with the land in sale, although there is no necessity of utilizing such water upon the land to which it was originally appurtenant, provided that by its transfer to other areas no injury is done to others who have a legal claim to water so diverted. Most Hawaiian streams seem to have been only incompletely utilized, in native taro production the unused surplus being the property of the person, usually the local chief, who acquired title to the ahupuaa in question. Rights to the surplus water, or the konohiki rights, form the controlling point in the ownership and distribution of irrigation resources. A large part of modern development has been made by securing such rights by purchase of the ahupuaa and the subsequent transfer of available water to areas which in early days had never been irrigated. Difficulties, of course, arise in the determination of the amount available for diversion in view of the ancient and well-established rights below the point of diversion. The same indefiniteness exists when old kuleana rights are purchased. In general, the amount of water involved in such cases has been determined upon the testimony of local witnesses, although the actual measurement of the water required for satisfactory taro production under local conditions is now a more common method. Waters arising upon government lands are leased for definite periods upon the terms secured at a formal auction.

Naturally, some aspects of the general conception require special consideration. In general, the boundaries of the ahupuaas were so largely governed by ridges and radial mountain spurs that the water resources of each might be readily determined. In some, however, the boundaries were quite arbitrary, and water rising on one ahupuaa may flow through another into the sea. In other cases, waters may rise partly on one ahupuaa and partly on another, the combined flow crossing a third before reaching tidewater. Questions involved in the ownership of such waters have not as yet been settled. Moreover, some authorities seem to believe that kuleana holders should be allowed some proportion of the surplus or freshet waters, since such waters, in early days, were used abundantly and with good results in native taro culture. Nor has the landowner's rights to ground water been adequately defined.

In spite of the comparative simplicity of the Hawaiian water code and its

success in developing the water resources of the Territory, the legislature in 1915 authorized the Governor (38) to appoint a commission to examine the water resources of the Territory and to "draft such legislation as may be deemed necessary by it to serve the best interests of the people of Hawaii." This commission, composd of G. K. Larrison, A. G. Smith and T. F. Sedgwick, secured the services of A. E. Chandler, for many years a member of the State Water Commission of California, and a well-known authority on water law. In his report, Mr. Chandler advised against additional legislation, apparently finding the local laws adequate for all future contingencies.

Developments Since the Mahele

Although the Mahele of 1848, with its promise of surety of land titles, should apparently have stimulated individual enterprise, the Hawaiian sugar industry declined rapidly immediately thereafter. A period of low prices beginning in 1852, coupled with a great drought in 1851, drove many of the smaller enterprises out of business. By 1857 the number of plantations had been reduced to five. Two of these, Lihue and Koloa, were on Kauai; two, the East Maui Plantation and one known as the Brewer Plantation, were on Maui; and the fifth was on Hawaii near Hilo. There is no record that any of these were irrigated plantations.

It is perhaps only natural that the promised, although as yet untried, security of land title, together with a devastating drought, should have turned attention toward irrigation. Eight years elapsed, however, before the first canal for the irrigation of cane was begun. During this period, W. H. Rice, for ten years associated with the Punahou School in Honolulu, became manager of H. A. Peirce and Company at Lihue. Although of New England ancestry, Mr. Rice early sensed the opportunities of irrigation and is reported as having remarked upon the fertility of the land of Oahu, "could water be applied," within only a few weeks after his arrival. Practical information in methods of irrigation and its possible results under local conditions was gained during his tenure at Punahou, since the school was largely self-sustaining as far as garden products were concerned. Abundant water for the gardens was secured from Punahou Springs and carried through the grounds in small ditches. Among the other plantings was a small block of irrigated sugar cane, located between the present site of Dillingham Hall and Punahou street.

With this background it is hardly surprising that Mr. Rice should early turn his attention to the possibilities of irrigation at Lihue. Here droughts seem to have been particularly severe. At times entire fields were cut back to the roots in order that the ratoon crop might take its chance in turn.

The first canal was not long nor costly, by present standards, but in view of the lack of tools and inexperience and the general lack of sympathy by Mr. Rice's associates, it was a tremendous venture. The canal is reported to have been eleven miles long and to have cost $7,000. Ethel M. Damon (7) gives April, 1856, as the time of beginning of construction. Letters of the period indicate that water was actually admitted to the Lihue field on August 16 of the same year. An old photograph of part of the first ditch on Kauai is shown on the cover of this issue. Although considerably enlarged, this canal, through the German Forest, follows the location of the Rice Ditch. The original photograph was taken between 1880 and 1890. The writer is indebted to Miss Damon for permission to use this print.

The period of drought seems to have continued, however, and a brief statement in *The Transactions of the Royal Hawaiian Agricultural Society* for July, 1856, indicates that continued dry weather made it impossible to divert water from the stream originally intended and that the canal was being extended to a "large and constant stream nine miles away." Other difficulties presented themselves, for a short note in the *Pacific Commercial Advertiser* for July 9, 1857, reports that the work was not yet completed, although great hopes were had for the following year.

Apparently these hopes were realized, for with the completion of this ditch the principle of gravity irrigation of Lihue and Grove Farm lands became established. Further developments under the capable hands of Paul Isenberg and G. N. Wilcox removed irrigation from the realm of speculative venture and established it upon the unquestioned basis of engineering principles.

In spite of the wealth of detail furnished by Miss Damon (7) with respect to the construction of these early canals, we find little in the records with respect to the actual distribution of water in the cane and the modifications of culture which must have been involved. It is hardly surprising, however, that the records are fragmentary. The Royal Hawaiian Agricultural Society, which began its short life in 1850, became inactive in 1856, after publishing seven annual volumes of *Transactions* which have become most valuable as source books. Sugar production was not generally considered of outstanding importance during the period of its publication, although Judge Lee (9), the founder, mentions "our great staples of sugar and coffee" in his address during the organization of the association. As has been indicated, the society discontinued publishing its proceedings at about the time that irrigation was being recognized.

However, casual phrases lifted from some of the addresses of annual chairmen indicate that the desirability of irrigation was at least being considered. For example, in the second volume of the *Transactions,* the Hon. Luther Severance (15) forecasts a time when " . . . the mountain stream must be carried in canals or aqueducts or lifted in small jets by the hydraulic ram. . . ." Two years later (1853) the annual address by John Montgomery (11) sounds a word of warning against the extension of irrigation and urges deep plowing and constant cultivation as a substitute. One of his phrases is particularly interesting. Here he says, " . . . the value of which (surface irrigation) I consider very questionable, as the soil saturated with a stream of water in summer and suddenly dried by a vertical sun, becomes so baked and consolidated as to be impervious to the roots of ordinary plants; and for this reason I have abandoned it." Where Mr. Montgomery had practiced irrigation is not clear.

It is not surprising that the possibilities of irrigating a crop so different from the widely grown taro should have escaped recognition at this early date. Large scale irrigation development in continental United States is commonly assumed to have begun with the Mormon migration to Utah in 1847. In view of the origin of the pioneers in Hawaiian irrigation and the distance involved, it must be assumed that the local development of irrigation, as an aid in commercial agriculture, was quite independent of that in Utah, and essentially concurrent with it.

Another interesting comparison between early Hawaiian development and that in continental United States lies in the debates over the virtues of irrigation which took place in each area some time before that practice became a recognized factor in crop production. The remarks of Judge Lee and Mr. Montgomery in 1851 and 1853 have already been mentioned. Discussion of the place of irrigation in agriculture in the United States was most bitter immediately prior to the passing of the Reclamation Act in 1904, almost forty years after the unquestioned success of gravity irrigation on Kauai.

The end of the active life of the Royal Hawaiian Agricultural Society in 1856 was practically concurrent with the development of the first gravity canal for sugar cane irrigation. By 1883, when the Planters' Labor and Supply Company was formed and its journal began the account of the development of the sugar industry, the economic justification of costly irrigation works for sugar cane had been established. The period of greatest interest in a study of the irrigation development in Hawaii is not covered by continuous printed record in any agricultural publication, although Thrum's Annual, published yearly since 1875, provides much information. References to water development in Mr. Thrum's Annual "Retrospections" are particularly illuminating.

But the period between 1856 and 1878 must have been one of considerable activity both in the organization of new plantations and in the development of irrigation resources by those which already were in operation. This transition was particularly well marked in the operations at Lahaina. Willfong's description of Parson's old mill at Lahaina has already been mentioned together with his statement that cane production was only incidental to taro growing. Moreover, the mill seems to have been moved to Makawao in about 1850. Apparently sugar milling was discontinued at Lahaina at this time.

Within the next twenty years significant changes took place, for in 1870 the partnership of Campbell and Turton, which for many years had been developing and operating a large tract of sugar cane land at and near Lahaina, was dissolved, control of the plantation ultimately passing to the Hackfeld agency. Since irrigation is essential to cane production in this region, it is evident that irrigation development must have been a significant and vital part of the company's program. Little is known of this development or of the method used for the actual distribution of water to the growing cane.

Whether or not development at Wailuku had been continuous since the early endeavors of Catalina and Hungtai, it is clear that three plantations were in existence near the mouth of Iao Valley in 1868 when Willfong became manager of the Wailuku Plantation. It is apparent, too, that irrigation was vital to all three, for Willfong (25) reports that "division of water (from the Wailuku River) during dry seasons, caused much quarreling which resulted in heavy law suits." Willfong also reports that he tried an "experiment" in 1875-76 which involved trenching before planting and striking a water level for each trench cut for placing the seed. He simply remarks that the method worked well but gives no further details, nor does he give any description of the method in use before that time. The similarity between Willfong's method and the general modern practice in the irrigation of cane is apparent.

Although developments at Lihue as well as at Lahaina and Wailuku were significant in view of the fact that they demonstrated the benefits to be derived from irrigation, they seem to have been relatively small projects for the most part, involving neither large capital nor great engineering resourcefulness, although the labor involved must not be minimized. In general, waters were utilized on the flood plains of their normal course. Since little is recorded as to the construction involved in the early works at Lihue, and nothing concerning those on Maui, it is probable that they were simple in design and employed no principle unknown to the natives.

A new chapter of development begins with H. P. Baldwin and S. T. Alexander, who demonstrated the feasibility of carrying water from regions of high rainfall across the difficult topography of East Maui for delivery to the fertile sun-soaked plains near Paia. Born of missionary parents at Lahaina in 1842, Mr. Baldwin must have had ample opportunity to judge the benefits of irrigation during his early life. Moreover, after graduating from Punahou, he returned to Lahaina in 1863 to work for an older brother, Dwight, who was growing cane for the Campbell and Turton mill. Although Baldwin's biography (3) contains no mention of irrigation during his cane-growing experience at Lahaina, it is highly probable that artificial watering was an essential part of the operation. It is also probable that further experience was gained during his service as head luna at Waihee.

It is clear, however, that the plantation organized by Mr. Baldwin and Mr. Alexander at "Sunny Side," above Paia, in 1870 was not irrigated. The first few years of this plantation were unprofitable, due, primarily, to scarcity of rainfall.

Since the abundant water resources of East Maui were not far away in miles, although remote because of engineering difficulties, a scheme of carrying this water to the lands around Paia soon suggested itself. This water, being under the jurisdiction of the government was secured by lease which ran in favor of a group of closely knit planters in the vicinity. In view of the difficulties involved, it is interesting to note that only two years were allowed by the conditions of the lease for completion of the project. If uncompleted by September 30, 1878, rights to the water were to revert to the government. It was initially estimated that the cost would not exceed $25,000. Financing was done by Castle and Cooke, of Honolulu. The complete cost greatly exceeded the estimate.

The difficulties of construction in view of number of men employed and the necessity of feeding them in remote camps, the organization required to order and install the great pipes used for the siphons and the building of flumes from native timber show the will and resourcefulness of Mr. Baldwin, who acted as superintendent of construction for the siphons and flumes, and Mr. Alexander, who directed the earth work. The work was completed barely in time to save the lease in view of its time clause. The reported cost was $80,000 in place of the estimated $25,000.

The effect of this work has been summarized by Arthur D. Baldwin (3) in his biography of his father. "The building of this ditch," he writes, "was an event of the utmost significance, not only to the island of Maui but to the whole group. In all the islands similar conditions existed, which the progressive planters began

to meet in the way which had been shown by Alexander and Baldwin on Maui. The results on that island have been impressive. The Spreckels, Lowrie, Koolau and other ditches have followed the Hamakua ditch, and Central Maui, which once was a bare waste, is now one of the most productive spots on the globe, supporting a prosperous population where formerly little existed besides the razorback hog, prickly pear and wild indigo."

The building of the Hamakua ditch of Alexander and Baldwin was quickly followed by another from the same general region built by Claus Spreckels. The Spreckels ditch is reported to have been the first step in a great scheme to water the Maui plains with the combined water resources of the East Maui and West Maui mountains. The estimated cost of the project was half a million dollars. Water was to be supplied to 17,000 acres of Crown land in Central Maui (37); subsequent developments have completed this plan.

These engineering successes upon Maui were followed by a few years of depression in the sugar industry, probably due initially to labor troubles, and which continued through 1887 because of an unsettled political condition. Although a ditch was proposed for the Hamakua district on Hawaii in 1883 (26), no significant gravity development was inaugurated during the period. However, the period was marked by development of interest in underground water resources and the discovery of an unquestioned artesian basin at Honouliuli.

James Campbell has been mentioned as one of the pioneers in irrigation and sugar production on Maui. With the returns from the sale of his equity in the Pioneer Mill Company, Mr. Campbell purchased two large tracts of land on Oahu, one at Honouliuli, including the lands of the present Ewa Plantation, and another more distant, part of which is now included in the Kahuku Plantation. For several years these areas were operated as stock ranches, water for the cattle on the arid plains being secured from natural springs.

In 1879 Mr. Campbell made a trip to California and seems to have visited the Santa Clara Valley in that state during the excitement caused by the discovery of underground water which might be tapped by shallow, inexpensive wells. At any rate, Mr. Campbell soon returned bringing with him a well driller named Ashley, from California, and his light, hand-operated well rig. This crude device was immediately set up close to the present site of Pump 1, of the Ewa Plantation Company. Artesian water, in the sense that water flowed over the top of the casing, was secured from a shallow hole. One of Ashley's wells, still in daily use, is shown in Fig. 10.

Other wells were at once proposed and in 1882 McCandless Brothers, of Honolulu, were engaged to drill a more pretentious well on the plain between the present mill site and Pump 1. Water was also found at this location, but due to the surface elevation, free discharge was not secured. The well was immediately enlarged into a vertical shaft and a steam-driven pump installed, the water being used for stock pastured on the higher lands. With the successful completion of another well in January of 1883, near the present Pump 3, the existence of extensive underground water resources seemed demonstrated.

The colonization of the Honouliuli lands by sugar, rice, grape and fruit growers was proposed in 1886 by a development company headed by James

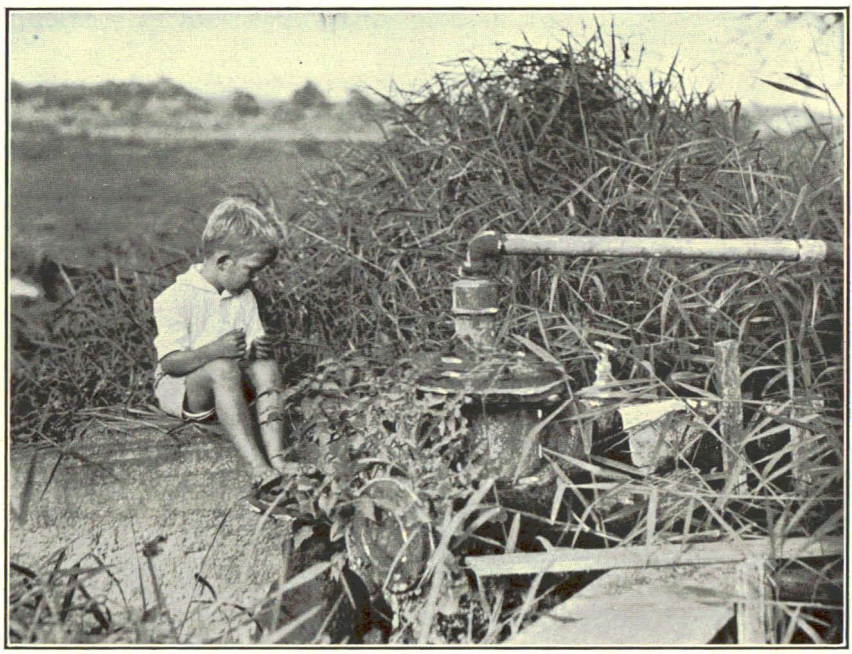

Fig. 10. Ashley's second artesian well at Honouliuli, Oahu. The first well is now capped and is in Field C of Ewa Plantation Company. This well supplies water for stock, the purpose for which it was drilled. (Photograph by the author.)

Campbell as owner and B. F. Dillingham as general manager. According to the prospectus issued at the time (27) small tracts of land were offered for sale for from $100 to $200 per acre for the best land, while grazing land was offered for $25 an acre. The conditions of sale were similar to those in force on many of the best land subdivision schemes of the present day. One of these conditions was that all tracts were to be substantially fenced, the company supplying the material and the buyer doing the work. Other restrictions were that a dwelling be built within six months and that a certain number of trees be planted to each acre purchased. Ten per cent of the purchase price was required upon the signing of the contract, the remainder being due upon a plan of deferred payments. Apparently each settler was expected to drill for and to develop his own irrigation water; at least there is no mention of a central irrigation agency in the prospectus.

Attractive as this plan of purchase should have been, in view of subsequent development, it does not seem to have been received with much interest in 1886, and few, if any, sales were consummated under it. Sometime prior to 1889, B. F. Dillingham authorized an extensive survey of the practice of irrigating sugar cane in Hawaii and of the water resources of the Honouliuli and Kahuku areas by the firm of Schuyler and Allardt, consulting engineers, of San Francisco. The report of this survey (16) reviews the practice of sugar irrigation as of that date and gives the first printed record of the amount of irrigation water required for the cultivation of cane at Hamakuapoko, Puunene and Wai-

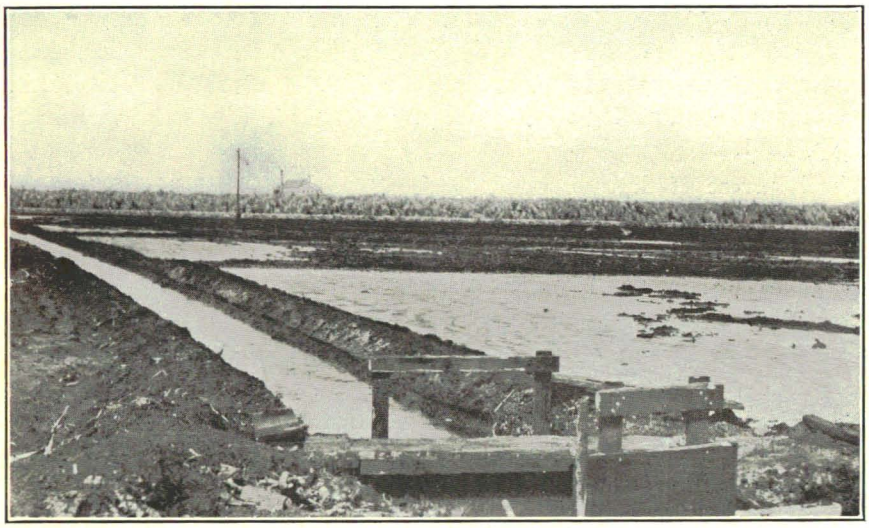

Fig. 11. Flooding of cane at Ewa Plantation Company. This practice, the forerunner of the modern border method, was used at Ewa when flat slopes made the standard contour line impractical. (Photograph by Ewa Plantation Company.)

luku on Maui and the Kekaha plantation on Kauai. The authors seem to have made their own measurements, using a current meter. It is interesting to note that the unit of measurement was the cubic foot per second per acre. Mr. Morrison, the manager of the Hawaiian Commercial and Sugar Company, is quoted as saying that sugar land could afford to pay $100 per acre for irrigation water. In conclusion, the authors reported favorably upon the underground water resources of the two areas of immediate interest and encouraged their development by steam pumps. Moreover, they suggested the possibility of developing gravity water near Wahiawa, tentatively locating a canal from their proposed dam site to the Ewa lands.

Although Mr. Campbell must have recognized the possibilities of sugar development upon his new holdings, he seems to have had little desire to participate actively in the work, for in 1890 both areas were offered for sale to, and later leased by, B. F. Dillingham for a long term.

These lands were soon subleased to corporations organized for the purpose of producing sugar. The Ewa Plantation Company was organized in 1890 and the Kahuku Plantation Company shortly after.

In the meantime H. P. Baldwin, while on a tour of Scotland, had secured a long time lease to a tract of land on the island of Kauai and upon his return in 1889 he turned his attention to the organization of the Hawaiian Sugar Company at Makaweli and the development of a supply of water in the Hanapepe Valley. The aqueduct, capable of delivering 60 M. G. D. (million gallons per day) was 13½ miles long, consisting of tunnels, open ditches, flumes and siphons, four of these being carried across the Hanapepe River on substantial iron bridges. Two miles of open ditch section were cut in solid rock. The reported cost was $152,000 (28). Although Mr. Baldwin had had no formal

training as an engineer, his judgment was so good and his experience on Maui so complete that G. F. Allardt, already noted as the associate of J. D. Schuyler, and a consulting engineer of San Francisco, engaged to consider the project before the work was begun, made no changes in the plans (3). The work was completed in April, 1891.

The influence of the new pumping development on Oahu is to be noted in a short account of the Hanapepe work in *Thrum's Annual* for 1892. Here the writer emphasizes the fact that the water was developed "at a cost not exceeding the first cost of a first class pumping plant doing equal duty and pumping 100 feet."

An interesting episode in irrigation development as applied to pineapples is to be noted in 1893, although this promising practice was soon abandoned and essentially forgotten. It is probable that the possibilities of irrigation as applied to pineapple culture were first noted by J. P. Keppeler, who, in November, 1893, irrigated an appreciable area in the Waiawa Valley, on Oahu. Water was secured from shallow wells and pumped to the point of use. The site of Mr. Keppeler's interesting venture is shown in Fig. 9.

The pineapple plants were grown in rows usually straight, but curving when the topography demanded. Rows were about two and a half feet apart, the plants being about a foot apart in the rows. Irrigation was accomplished by running a small stream of water in furrows drawn between the rows. The plants were irrigated every ten days.

Remarkable yields, both in fruit and in planting material, are reported from this area. Mr. Keppeler indicates that fruits weighing from 12 to 15 pounds were common, and that mature fruits were secured in from 14 to 18 months. Since the practice of canning the product locally was still in its infancy, fruits from this area were carefully packed in straw and shipped to brokers in San Francisco. Despite the excellence of the product, the venture was not profitable.

Other growers became interested, however, and the practice of irrigation as applied to pineapples spread slowly into other near-by areas and to Wahiawa, primarily due to the activity of Byron O. Clark. Subsequent developments at Waipahu eliminated the plantings of Mr. Keppeler and his associates at Waiawa, while irrigation may not have been economically essential at Wahiawa. In any event the practice of irrigating pineapples seems to have been short-lived. There is some evidence that irrigation as applied to this fruit was considered on the lands of the McBryde Sugar Company on Kauai at about the same time.

Still another period of depression in the sugar industry set in soon after the incorporation of the two sugar plantations on Oahu and the completion of the Hanapepe ditch on Kauai. Low prices for sugar, due to the McKinley bill, forced some established plantations out of business, while others turned their attention to increasing production upon the areas already under cultivation in place of expanding. Moreover, labor conditions are reported as unsatisfactory.

Low prices and insecure labor conditions soon suggested an agricultural experiment station in which the common problems of the industry might be studied upon a cooperative basis. Such a laboratory was established in 1895 under the able direction of Dr. Walter Maxwell, who resigned from the U. S.

Fig. 12. Waimanalo ditch, Ewa Plantation Company, before lining. Increased appreciation of the value of water focused attention upon the losses which must occur in such ditches. (Photograph by Ewa Plantation Company.)

Fig. 13. Waimanalo ditch, Ewa Plantation Company, after lining. In addition to curtailing seepage losses, such linings increase the ditches' capacity. (Photograph by Ewa Plantation Company.)

Department of Agriculture to accept the post. The studies of the newly organized station along the lines of irrigation investigations as well as similar studies by the plantations themselves have been summarized by Alexander (2).

Better conditions for the sugar industry followed the establishing of the Experiment Station. Increased sugar production per acre brought profit to plantations which had lived over the period of depression; the labor situation was improved; new plantations were proposed.

Since it marked the trend of the times, the most interesting development during the nineties was the organization of the Oahu Sugar Company on the island of Oahu in 1896. This plantation was located, to a large extent, upon Campbell land and was dependent, initially, upon irrigation water pumped from wells similar to those which supplied its neighbor, the Ewa Plantation.

In view of lack of precise information as to the cost of pumping in Hawaii, promoters of the Ewa Plantation Company had leased only the low level lands of the Honouliuli ranch, the upper boundary being marked by the 200-foot contour. Prompted by the success of this company and encouraged by more reliable figures as to the costs involved, the Oahu Sugar Company, in addition to other lands, leased a strip above the Ewa Plantation extending to the 650-foot contour. That the economic pumping head for irrigation, if the entire supply is to be pumped, lies somewhere between these limits is evidenced by the fact that pumping by the Oahu Sugar Company has never extended to the upper edge of this strip.

Well boring for the new Oahu Sugar Company began immediately after organization and by 1897 was so far advanced that planting at a rate of 50 acres a day was possible (29). Fig 15 shows a low-lift, high capacity pump at Ewa Plantation Company.

These new successes on Oahu again prompted interest in pumping for irrigation. New plantations were begun on Lanai and Molokai with the idea of securing irrigation resources from an underground supply, while Waimea on Kauai, East Maui on the island of Maui, and Kohala on Hawaii sank wells to supplement the supply secured from stream diversion. The Honolulu Sugar Company and the Waialua Agricultural Company, both on Oahu, were organized at about the same time. Initially, the entire water resources for these plantations were secured from wells, although gravity water was soon secured as a supplemental supply.

The turn of the century introduced a period of high prosperity for those Hawaiian sugar plantations which had weathered the difficulties of the nineties. Annexation promised freedom from the constant threat of an exclusive tariff by the United States, while more settled labor conditions were hoped for at the time.

Consequently, the number of plantations increased, while many of those already operating increased their capital stock to finance expansion and betterments not previously justified. Although several of the newly formed plantations must have been irrigated from the beginning, no new principle seems to have been involved nor were the irrigation works developed for them of sufficient magnitude to justify mention in the public records of the period.

Fig. 14. Seed cane being irrigated by the long line method at Wailuku Sugar Company, Maui. The galvanized iron intake structures permit the careful control of the water. (Photograph by Wailuku Sugar Company.)

The promised prosperity of 1900 was reflected on the island of Maui by the construction of a new canal from East Maui by the Alexander and Baldwin interests in 1901. This canal, still called the Lowrie ditch, had its intake at the same point as the old Spreckels ditch, already mentioned, but due to better location and to the heavy construction involved delivered water at an elevation of about 450 feet above sea level at Spreckelsville. The original capacity of the ditch is reported as 60 M. G. D. The reported cost was $225,000. Since the right-of-way traversed lands of the Paia Sugar Company and the Haiku Sugar Company, rental in the form of one-tenth of the water conveyed was paid by the Hawaiian Commercial and Sugar Company to the two sugar companies involved. This water was subsequently divided between the Paia Sugar Company and the Haiku Sugar Company, eleven-twentieths of the amount going to the former and nine-twentieths to the latter. The writer of the contemporaneous account (19) again mentions the economic advantages of gravity diversion.

Major engineering construction was rapid in the first decade of the new century. The need for an additional water supply upon the Makaweli Plantation on Kauai was met by the construction of a 13-mile canal from the Olokele Valley by the Baldwin interests. M. M. O'Shaughnessy, later to be Chief Engineer for the city of San Francisco, was in charge of location and construction. This canal had a reported (30) capacity of 75 M. G. D. and cost $320,000.

The expansive spirit of the time was evidenced on Maui by the beginning of a 20 M. G. D. canal from Honokohau by the Pioneer Mill Company, and another great canal from the Koolau district on East Maui to serve the Hawaiian Commercial and Sugar Company, which had become an Alexander and Baldwin enterprise, and the Paia and Haiku Sugar companies. The Koolau ditcth, carrying 80 M. G. D., built under the direct supervision of O'Shaughnessy, was particularly remarkable in the great length of rock tunnel involved. About seven and a half miles, out of a total length of ten miles, are said (31) to be in tunnel section.

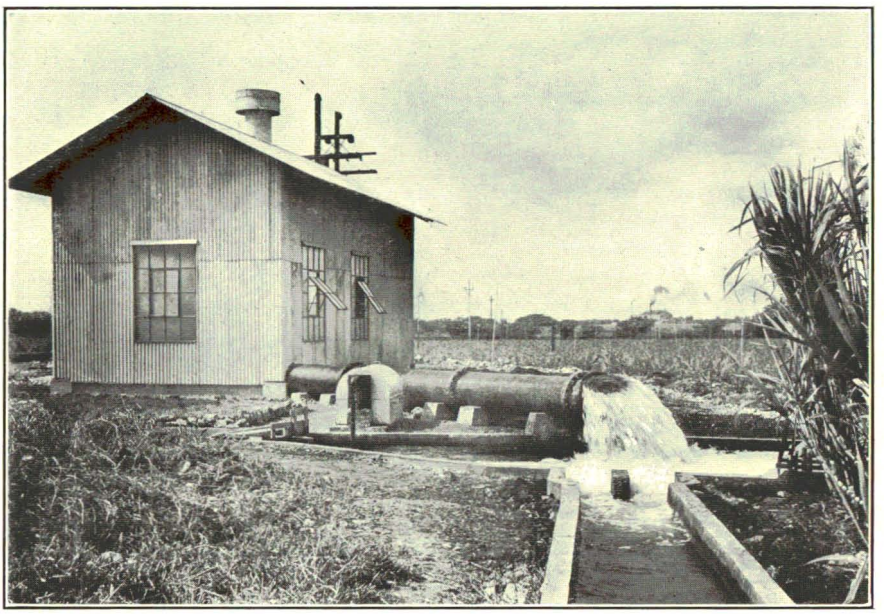

Fig. 15. A typical low-lift, high capacity pump at Ewa Plantation Company. This pump delivers 14 cubic feet per second from a shaft 43 feet deep. (Photograph by Ewa Plantation Company.)

An unique and economical method of developing water in Hawaii finds first printed mention in a short article on irrigation in the Territory by Mr. O'Shaughnessy, published in 1905 (13). This method, in common use at present, involves the driving of tunnels into lava formations at relatively high elevations, the seepage water and water released by the interception of lava tubes, which may carry relatively large flows, being led on a natural gradient to the tunnel portal and the point of use. O'Shaughnessy notes a recovery of 2 M. G. D. by a 500-foot tunnel at an elevation of 1400 feet at Waianae on Oahu. and 6 M. G. D. at Lahaina, Maui, from a tunnel 2600 feet long. In both these cases the author notes that the outward formation showed no sign of water resources. Experience, probably gained on the Olokele and Koolau ditches, prompted O'Shaughnessy to remark, however, that many long aqueducts, driven in territories as promising as those noted above, showed no sign of water interception. A short summary of the capital investment in irrigation work in the Territory up to 1905 is included in Mr. O'Shaughnessy's paper.

Waldeyer (23), in 1910, cited the necessary conditions for success with water development of this sort and listed the successful ventures between 1905 and 1910.

In the arduous and oftentimes dangerous work of tunneling the Japanese seem to have been particularly active. Yasutaro Soga (17) remarks upon the aptitude of the Japanese, particularly those from Fukuoka and Kamamoto prefectures, for this sort of work in the *Nippu Jiji* for February 14, 1932. These men, due to native courage and resourcefulness, have contributed largely to the water resources of the Territory by hard rock tunneling. Particularly out-

standing is Nitaro Kawano, who in 1903 was responsible for the actual construction of the 24 tunnels on the Olokele project.

Additional water development for the Wailuku Sugar Co., which had resulted from the amalgamation of the three smaller companies on the eastern slopes of the West Maui mountains, was under way during the expansive period. This work involved the diversion of more water from the Iao Valley and its distribution over the fertile plains at the valley mouth.

Although Schuyler and Allardt (16) had called attention to the possibilities of gravity water storage near Wahiawa, Oahu, in 1889, no development was begun until about 1900. Seven years of effort in this area and the investment of $300,000 resulted in the completion of the Wahiawa dam in 1907. This dam, constructed by an independent water company, stored the drainage of 8000 acres and doubled the area of cane land irrigated by the Waialua Agricultural Company, to which organization most, if not all, the water is sold. A description by Thomas (20) gives the information that water from this reservoir was sold for one-third of a cent per hour for each miner's inch, or $6.17 per million gallons. Although no mention is made of which of the many miners' inches is intended, the equivalent value suggests the unit in common use in Southern California, where a miner's inch is taken as one-fiftieth of a cubic foot per second. This reference to the miner's inch as a unit of water measurement is the only one in which this inconvenient and highly artificial unit is encountered in the literature of water development in Hawaii.

One of the few cooperative ventures in water development in the Territory was begun at about the same time and promised additional water resources for the Wailuku Sugar Company and the Hawaiian Commercial and Sugar Company, on Maui. The interests of these two companies in the new Waihee

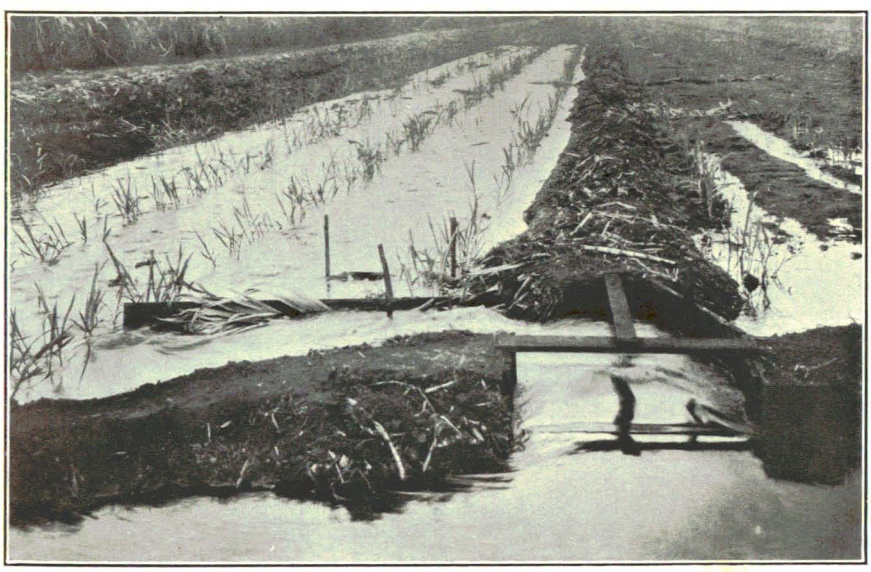

Fig. 16. The border method at Ewa Plantation Company. This system of applying water has resulted in phenomenal savings in the labor of irrigating. (Photograph by Covell, Honolulu.)

canal, completed in 1908, are reported (32) as being seven-twelfths for the Wailuku Sugar Company and five-tweflths for the H. C. and S. Company. The original construction involved more than 10 miles of ditch, 22 tunnels and a 3-foot steel siphon across the Iao Valley. The reported cost was $160,000. Modern use of this cooperative canal grants the use of day water to the Wailuku Sugar Company, while night water, stored in reservoirs near Wailuku, is available to the H. C. and S. Company.

Another outstanding development of the period was the construction of the Kekaha-Waimea canal of Kekaha Sugar Company, which tapped the Waimea River on Kauai. No diversion dam was required, in this work, the intake being through a rock tunnel which enters a deep pool in the bottom of the river at an elevation of 550 feet. Sixteen miles of canal and tunnel sections carry 45 M. G. D. to Waiawa gulch where the main canal ends. Surplus water is used for power development. The reported (32) cost was $275,000.

In the meantime developments and expansion at the Oahu Sugar Company had increased the demand for water to such an extent that the pumping lift, for some areas, had reached 550 feet. The desirability of a supplemental gravity supply was evident, but all near-by streams were small and intermittent and consequently inadequate for the purpose. The only available source of water seemed to be in the Waiahole, Waikane and Kahana streams on the windward or "rainy" side of the island of Oahu and separated from the Oahu Sugar Company lands by the main mountain ridge of the island. Many reports had been made, from time to time, upon the feasibility of such an ambitious under-

Fig. 17. Long line planting at Ewa Plantation Company. This method of planting and irrigating is useful on steeper slopes and more difficult topography than the border method. Great economies in labor have been effected by this system. (Photograph by Covell, Honolulu.)

taking by Mr. O'Shaughnessy, J. B. Lippencott, later to be chief engineer for the city of Los Angeles; J. Jorgensen, a local engineer, and others. The report of Mr. Lippencott (36) seems to have had greatest publicity and is quoted as having declared the scheme feasible but costly. The original estimate gave the probable cost as $1,500,000.

The need for water was great, however, and the Waiahole Water Company, organized in 1912, began work on the tremendous undertaking in February, 1913, in accordance with plans prepared by Mr. Lippencott. H. K. Bishop, appointed chief engineer at the beginning of the venture, resigned in October of the same year and was replaced by Mr. Jorgensen, who carried the work to a successful conclusion.

The construction of the main tunnel almost three miles long was marked with greatest difficulty. Mr. Jorgensen describes the construction in an unpublished report prepared for the Army in 1918. Here he says in part:

> Rain water had saturated the intervening porous lava rock with the result, that an easy outlet being afforded by the tunnel bore, a great flow of water was obtained when these dykes were penetrated. Dykes of this description were encountered from within 200 feet of the portal for a distance of about 4000 feet with intervals of various lengths of ordinary lava rock. At first the developed water was taken care of by ditching below the tunnel floor, but as the water increased after each dyke penetration, other methods had to be resorted to, the slope of the north tunnel being downwards. At a distance of 900 feet from the portal the flow had increased to 26 million gallons per 24 hours, and the men were working in water up to their waists, the drain ditch being unable to carry the water off, although 5 feet below the floor. The water poured from the top, sides, bottom and face with a pressure of 65 pounds per square inch in drill holes, necessitating impounding the explosives in tin cylinders and anchoring the charges in the holes. A sump was finally made close to the face and a 16-inch wood stave pipe installed as a siphon, which was later augmented by another 20-inch siphon placed on top of the 16-inch one. New sumps were made as the work progressed. At 1400 feet from the portal the water had increased to 36 million gallons per 24 hours and the siphons were unable to carry off the water, and it was finally decided to excavate a tunnel on the side of and a few feet above but parallel to the main tunnel and on an up-grade, with short lateral tunnels extending over the roof of the main tunnel. As the main flow of water came from above it was calculated that this tunnel and its laterals in this way would catch most of the water, and by driving the two tunnels simultaneously, make it possible for the men to work. This plan succeeded for a distance of 300 feet, when it was found necessary to excavate a sump in the main tunnel, install a centrifugal pump of 13 mil. gal. capacity and pump this amount of water to the upper tunnel, which at this time was 18′ above and 25′ on one side of the main tunnel. By this means slow progress was made till the south bore was met at a distance of 3200 feet from the north portal. At the south portal rapid progress was made after the installation of the proper machinery and electric storage battery locomotives were in service for hauling muck-cars. No effort was spared to get speed in this heading and the average progress maintained for a long time was 21 feet per 24 hours, as high as 684 feet in one month was obtained.

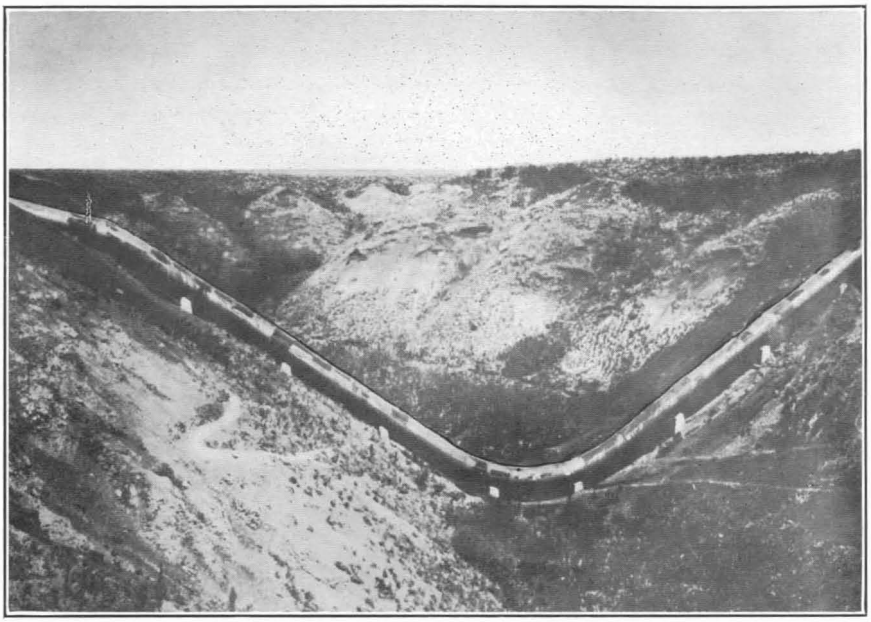

Fig. 18. A great siphon on the Waiahole Ditch. Such siphons as this cross the gulches between the tunnel portal and the agricultural lands of the Oahu Sugar Company. (An unidentified photograph in the files of the Experiment Station, H. S. P. A.)

Mr. Jorgensen's estimate of final cost is $2,000,000, not including the water rights which naturally had to be acquired.

A similar but much more dramatic account, containing a well deserved tribute to Mr. Jorgensen's engineering skill and resourcefulness, is to be found in *Thrum's Annual* for 1916 (33). Part of the heavy construction on the Waiahole ditch is shown in Fig. 18.

This expansive period was naturally marked with increased water demands on other plantations as well. Honolulu Plantation Company constructed a tunnel in Waimalu gulch as well as a small reservoir, while the Pioneer Mill Company began a new tunneling project similar to those reported by O'Shaughnessy (13). On Kauai plans were made to develop water in Wailua stream to supply homesteads in the vicinity and to augment the supply for the Lihue Plantation. By 1920 the Oahu Sugar Company had plans for additional pumping. Although the plantations on East Maui had long taken the lead in gravity water development, the convenience and flexibility of pumping had not been overlooked. In 1923 the Maui Agricultural Company, resulting from an amalgamation of the Haiku and Paia plantations, is reported (34) as having installed a steam-turbine-driven high lift displacement pump with a capacity of 12 M. G. D. The total lift of 751 feet is reported as being the greatest in the Territory.

The year 1924 saw the completion of the latest great gravity development in the Territory. The Wailoa ditch, built by the Hawaiian Commercial and Sugar Company and the Maui Agricultural Company, once more tapped the great water resources of East Maui. Diverting the waters of Nahiku stream, 30

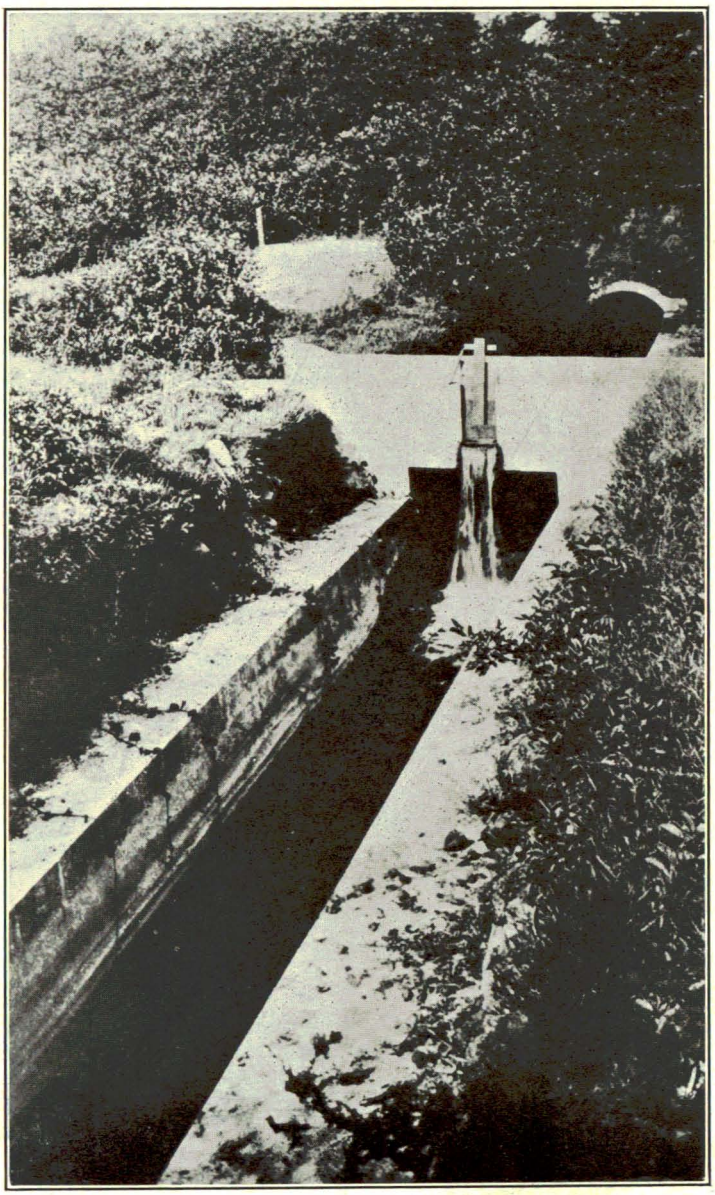

Fig. 19. Kauhikoa Ditch. This canal from the great water resources of east Maui is typical of the heavy irrigation construction in that area. (Photograph from "The Kauhikoa Ditch," by Collins.)

miles away, the Wailoa canal supplies 145 M. G. D. through the largest canal in the islands. It is concrete-lined throughout. Emerging upon the Maui plains at an elevation of 1100 feet, it supplies gravity water to a large area previously supplied by pumps (35).

As has been noted, irrigation development has been largely affected by economic conditions, periods of high sugar prices being reflected in increased interest in water development. Naturally the low prices of the present result in curtailment of expansion. One large project, involving gravity water storage by a hydraulic fill dam for use on the McBryde Sugar Company, has recently been completed. This dam has drawn much favorable comment in the engineering world because of its advanced design.

It is well recognized that this brief history of the sequence of irrigation development in Hawaii cannot be complete. Behind the general pattern outlined above lie many minor schemes, some of which are too local to influence general trends, while others, such as the pumping ventures on Lanai and Molokai, seem to have been complete failures. Moreover, the consistent increase in the use of pumping units to supplement a gravity supply and the remarkable use of intercepting tunnels in one form or another found little mention in the records of the period after their novelty had worm off. At best this description of development outlines simple trends.

Plantation Utilization of Water

As has been indicated, little is known of the methods actually used for the distribution of water to the cane fields at Lahaina in the early days of irrigation. Presumably cane was planted in level lines and irrigated by admitting water from a ditch at one end. But there is no evidence as to how long these lines were. We do know, however, that the irrigators at Pioneer Mill Company worked in teams of two. One of these men turned the water into each line while his teammate waited for its appearance at the far end. When the line was full, this observer called "piha," or full, and the water was turned into the next line. The operation was then repeated.

C. A. Buchanan, for many years associated with the Pioneer Mill Company, tells that this practice continued until operations of this sort took place for an entire night under Mr. Campbell's bedroom window. Lack of sleep resulting from the frequent calls of the irrigator's assistant prompted an investigation in the morning; as a result, the irrigator lost his helper. Many years passed before a further labor reduction of 50 per cent was possible in irrigation.

How the method used at Lahaina differed from those adopted at Wailuku as a result of Willfong's "experiment," which has been mentioned, is not known. Nor do we know how either of these differed from the method of level lines introduced to Grove Farm by G. N. Wilcox and subsequently adopted by the Kauai plantations.

It is clear, however, that the common method used by most, if not all, irrigated plantations at the beginning of the century, involved planting cane in furrows about five feet apart, these furrows being so located that each followed a contour

line. In general, water was supplied to the lines by "watercourses" drawn at right angles to the contours and consequently at right angles to the cane rows. These watercourses were about 35 feet apart and secured their supply of water from larger ditches, which crossed the fields on flat grades at intervals of 200 to 300 feet. The success of this method, which proved its worth through many years of service, provides a commentary on the properties of Hawaiian soils. Few mainland soils could withstand the erosive effect of water on the steep grades used in the watercourses under local practice.

Desirable as the standard contour line may have been, attempts were made to better it, either by modifying the general scheme toward the end of reducing the labor involved, or reducing the amount of water used at each application. In some cases still another improvement was sought, that being an increase in the flexibility of operation so that freshet water might be expeditiously but perhaps unevenly applied during its few hours of availability.

Naturally in view of the different ends desired by different plantations, many modifications were suggested and tried, often with considerable success. Alexander (2) describes many of them.

Except for one or two of these modifications of the contour line method, which are of greatest value in the handling of freshet flows, all these schemes involved trapping water in a closed level furrow and allowing that water to seep into the soil without respect to the time required.

Another chapter in the story of improvements in irrigation practice begins with the use of methods involving the introduction of water at the top of a slope and letting seepage into the soil take place only while water is flowing over it. Although of long usage in Continental United States, the first use of this general principle in Hawaii is reported as beginning in 1921 (2). Here the cane was planted in lines on the usual spacing. But in place of running with the contours, these lines ran at right angles to them. Water introduced into the upper end of the lines naturally flowed down the lines under the influence of the slope, irrigating the plants as it reached them. When the water was turned out of the line seepage stopped, excess water flowing out of the line into the next supply ditch.

Apparently the general scheme was conceived independently as far as local practice is concerned, and almost concurrently at Ewa Plantation Company on Oahu and at Kilauea Sugar Plantation Company on Kauai. At Ewa the method called the "No Watercourse System" for obvious reasons was not particularly successful, at least no large area was irrigated by this means. But at Kilauea, under the guidance of L. D. Larsen, at that time manager of the plantation, the system soon proved its worth and had become one of the methods in common use by 1932. Details of labor and water economies effected by this method are to be found in the annual reports of the Hawaiian Sugar Planters' Association for 1931 and 1932. Two examples of long line planting are given in Figs. 14 and 17.

In the meantime the conditions at Ewa had directed attention in quite a different direction. Since some of the fields on this plantation are extremely flat, great difficulty was experienced in keeping water in the watercourses during the irrigation. Despite every possible care, water escaped from this ditch, and the situation became worse as the cane grew, increasing the resistance to flow and requir-

ing a greater head in the watercourse. About 1925, a new policy was adopted for such fields. Large areas were enclosed within substantial levees and the enclosed area flooded in much the same manner as rice or taro, except, of course, that no long-continued submergence was permitted. The yields of these fields were surprisingly good as measured either by cane or sugar, and although it may have been wasteful with respect to water used, it was markedly economical of labor (Fig. 11).

Naturally, this method of flooding was only suitable for flat fields, but the success gained in such areas prompted an enthusiastic trial of the border method so long used in the irrigation of alfalfa and field crops in the irrigated West.

This method involves enclosing long narrow strips of land which run down a slight but significant grade. These strips or borders, as they are almost universally called, are level from side to side and, in normal Hawaiian practice, carry four rows of cane, these rows being parallel to the long axis of the border. Water admitted to the top of the border spreads from side to side since the border is level in that direction and moves down the border in a thin sheet under the influence of the slope. At Ewa, this method has been highly successful, amazing labor economies having been effected. Fig. 16 shows a border being irrigated. Frequent descriptive accounts of the procedure, as well as cost figures, have appeared since 1928 in *The Hawaiian Planters' Record,* the *Reports of the Association of Hawaiian Sugar Technologists,* and in papers prepared for presentation at the annual meetings of the Hawaiian Sugar Planters' Association.

An ever-increasing appreciation of the value of irrigation water has been responsible for many forms of ditch linings. Some linings, particularly those in large canals of continuous flow, are of monolithic concrete, while other ditches are of hand-faced stone cut from local rock and set in cement mortar. In general the availability of suitable stone and the semi-skilled labor required has been a large factor in determining the type of lining used. Typical ditch sections before and after lining are illustrated in Figs. 12 and 13.

The lining of the smaller field ditches presents a more difficult problem and one which has been attacked in many ways. At McBryde Sugar Company pre-cast concrete slabs have been used, while at Hawaiian Commercial and Sugar Company a thin plaster lining of cement on poultry wire reënforcing is being tried once more after the previous failure of this method according to plantation tradition. Many forms of oil linings have been attempted with varying degrees of success. One method involving the use of a proprietary compound of asphalt has given some promise. The ideal ditch lining material for all conditions, if any exists, has apparently not been discovered. Developments within the next ten years should contribute materially to this field of irrigation improvement.

In the field of plantation improvement in irrigation practice, the perspective of the present does not lead to sound judgment of trends. A writer ten years hence may trace the development of these practices with much greater confidence due to the precise records of the present and to the wealth of descriptive material, which is now being made available.

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