Water conservation in Curaçao; using traditional earthen dams

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Abstract

The climate in Curaçao is semi-arid to arid. Every century several extended periods of drought occur with practically no rain. A whole system of earthen dams for water conservation was developed since early colonial times. This system was developed and constructed by the Dutch, it is not found in the Spanish Islands. These dams force part of the rainwater into the ground and help maintain groundwater levels; they also help to combat erosion. A large number of smaller dams is more effective than a few large ones. This way ground water levels are influenced over a relatively large area. A few larger ones were constructed in the 20th century but even so these are relatively small; the very largest one having a capacity of 600.000 tons. The next one comes in at 450.000 tons; all the others are substantially smaller. The larger dams are less effective, they store more water above ground in a deeper temporary lake where a larger fraction of the water is subject to evaporation over a longer period of time as compared to a series of smaller dams with the same capacity.

Since most of the food production was local, this system was of the utmost importance. Curaçao is divided in 48 different watersheds (catchment areas). With time the water flows in practically all of these were all extensively dammed, except for the limestone and calcareous areas. Housing developments have lead to the destruction of many dams. There are still a few large ones and about 800 smaller ones which are still functioning. In the past there were at least 1500 of such dams.

1. Rainfall

The climate in Curaçao is semi-arid to arid. The island has a surface area of 444 km2. Its climate is rather arid compared to most Caribbean islands, with a mean annual rainfall of 557 mm (Meteorological Service of Curaçao). The hilly areas in the western part of the island receive slightly more rain, and rainfall can be quite variable from year to year. Dry years have only 200-300 mm of rain, while the maximum is about 1100 mm. The driest year on record for Curaçao is 1914 with an average of 207,9 mm. Every century several extended periods of drought occur with practically no rain (van Buurt, 2010). These can last up to 24 months or even longer. The indigenous species of fauna manage to survive such long periods of drought, although mortality can be high. Other indigenous species, such as for example the land snails Cerion, Tudora and Drymaeus cope quite well and are able to survive such extremely long dry periods, when the bush shrivels and even some cacti die. During the early 20th century there were several extremely dry years, there was a famine, and many Curaçao men fled to Cuba to work in the sugar industry. Since the drought also extended to the northern parts of Venezuela, it became more difficult to import food from Venezuela and food prices went up. In the Netherlands money was collected to send food to Curaçao. At the time Curaçao was extremely poor. It is known that further in the past similar long extended dry periods have occurred, but no rainfall data are available for these early colonial periods. In 1743 for example several Indian (Caquetío) families were transported to Venezuela by the Dutch West-India Company (WIC), since there was insufficient food available. Presumably it was less costly to deport them from Curaçao, than to buy food for them; which would have been needed to feed slaves. Several times each century extremely dry periods of two or three dry years in a row and more rarely, four succeeding dry years occur (See Table 1). For Curaçao rainfall data are available since 1830, with short interruptions from 1875-1883 and from 1892-1894, the dry periods also extended to the other islands of Aruba and Bonaire, and parts of Northern Venezuela, rainfall patterns being very similar.

Extended period of drought	***Precipitation in mm/yr***	***Extended period of drought***	***Precipitation in mm/yr***
1841-1843	272 290 408	1947-1948	301,2 421,1
1868 -1869	226,2 296	1958 -1960	287,4 Hato 280,6 355,8 Hato 282,2 363,3 Hato 482,8
1898 -1900	479,6 357,7 437,4	1977-1978	355,5 Hato 270,5 389,2 Hato 271,1
1902 - 1905	313,4 382,3 473,9 413,6	1982 -1983	380,5 340,1
1919-1920	270,3 301,4	1986-1987	321,2 369,3
1929-1930	323,2 269,1	2001-2002	331,4 331,8

Table 1. Extended dry periods, 1830-2004, data for Curaçao (Meteorological Service of Curaçao).

The data were interrupted from 1875-1883 and from 1892-1894. Data before 1954 are a weighted average of several locations on the island, after 1978 only the data at Hato airport are given. In this table both values are given for 1958 to 1978. The Hato location is usually somewhat drier than the weighted average. Monthly data, which unfortunately are not available for the early years, give a better view of the true extent of the dry periods. The 2001-2002 dry period (so named based on the yearly values) for example, based on monthly data lasted till the end of September 2003, it thus lasted 2 years and 9 months. The 1982-83 dry period lasted till the end of September 1984. It also lasted 2 years and 9 months. A very dry period with one rain shower exceeding 70 mm, which will cause trees to green and grass to sprout, will bring some relief and such a dry period will be less "stressful" than a year with the same amount of precipitation spread out more evenly. The 1958-1960 dry period, started at the end of November 1957 and was interrupted by a rain shower of 104,3 mm (Hato airport) in January 1960, then the dry period went on till August 1960, with more rain following in October 1960. If we compare the Hato data with the weighted data for 1960 this strongly suggests that the 104,3 mm shower fell at Hato only. The rest of the island had a long dry period of 2 years and 8 months.

Sta. Cruz, rainy season, 2004

Sta. Cruz, dry season, 2007

2. Temperature

The mean temperature is about 28°C. The lowest temperature measured in Curaçao during the last 30 years was 19°C. Air temperatures vary between Av. (average) 26.5°C in January and Av. 28.9°C in September. The last week of January and the first week of February usually have the coldest air temperatures with an average of about 26.5°C. Sea water temperatures vary between Av. 25.9°C in February/March and Av. 28.2°C in September/ October (data: Meteorological Department of Curaçao, period 1971-2000, on request). In comparison to other arid areas in the West-Indies yearly average temperatures are higher in the Dutch Leeward islands, since winter temperatures are much higher.

3. Evaporation

Evaporation is very high. In the salt pans of Bonaire a yearly average of 8,4 mm/day per year is measured (Bonaire Salt Company; see de Palm, 1985). In the Curaçao dams which are exposed to less wind, since they are inland, somewhat protected by the dam and surrounded by vegetation, evaporation is probably between 4-6 mm per day, which is still quite high. The evaporation rate is difficult to determine precisely, since all sorts of animals such as insects, birds, bats, and occasional lizards will help themselves to the water in the evaporation pan (not to mention the occasional feral pig, burrowing beneath the outer fence), especially during the dry season. At the Bonaire location such animals are not present. Fencing the evaporation pan off completely will however reduce evaporation and will also give skewed readings.

4. Salt in the air

In Curaçao the trade winds are usually strong. The yearly mean wind velocity is 7.1 m/s (Beaufort 4). In June winds are strongest with a mean of 8 m/s. The prevailing direction of the winds is between 0700 – 1100; usually winds are due East (900) (data: Meteorological Department of Curaçao, period 1971-2000, on request). The sea on the northern coast is quite rough and many little drops of water are blown off the waves; such droplets evaporate and the air is heavily laden with small salt particles; such salt particles carry very far and are blown all the way across the island. On their North and East coasts the islands are almost continuously exposed to strong winds coming in from the sea. The sea in this area is notorious for its short wavelength choppy waves, which makes for a rough ride in small vessels. This salt is even deposited on the windward sides of highest tops of the island. The Seru Gracia, with a height of 297 meters is the second highest hill in Curaçao, the shrub *Gundlachia corymbosa* (yambush, Jamaica thrash), which is considered a halophilic plant, is growing on the windwardside of the top of this hill. This is at a shortest distance of 3.8 km from the sea, while when measured in the direction of the prevailing easterly winds, the distance salt would have to travel is more than 6 km. On the top of the Sint Christoffel mountain, which at 376 meters is the highest peak in Curaçao, *Gundlachia corymbosa* is also found.

Photo: Corry van Heijningen

The halophilic plant Gundlachia corymbosa (Yambush or Jamaica thrash), growing on the windward side of the top of the St Christoffelberg (376 m asl.), the highest elevation in Curaçao (left picture) and also on the windwardside of the Seru Gracia, (right picture) the second highest elevation in Curaçao (297 m asl.)

5. Vegetation

The vegetation is typically xeric with for example: candelabra cacti, opuntia's, melocactus, dyewood, lignum vitae and acacias. During the rainy seasons of wet years parts of Curaçao can be surprisingly green.

6. Earthen dams and wells

In view of the difficult climatological conditions, a whole system of earthen dams for water conservation was developed early on. Since most of the food production was local, this system was of the utmost importance. Curaçao is divided in 48 different watersheds. With time the water flows in practically all of these were all extensively dammed. The limestone or calcareous areas are very porous and in these areas there is no surface run-off at all. In these areas there are no dams. The areas with volcanic soils (the so called Curaçao lava formation, consisting of basalts and pillow lavas), were all utilized and some of the areas with alluvial soils as well. The term "dam" in Curaçao refers to both the dyke and its reservoir.

Usually there is masonry protection of the dam ends. The somewhat larger dams often have more elaborate overflow structures (spillways) as well. Those on Government owned land are maintained by the Curaçao Government. In the Curaçao lava formation the soils are permeable and the water in the dams penetrates into the ground fairly rapidly. Usually there is a hand-dug well right behind the dam, or/and within the area of its reservoir. Many of these are about 20-25 meters deep. When the dam dries out, these wells will still hold water for a long time (usually up to two years) and will be rapidly replenished when the rains start.

Masonry protection of dam ends. Usually the dam ends are protected. Larger dams also have overflow structures.

In these pictures the dam body has slumped and has been eroded through the years. The dam end protection of dam 132 (top left, taken in 2016). This dam was constructed after 1908 (it was built as part of the dam-building activity plan by Ir. M.C. Fauel, 1908). The dam head has been undercut by overflowing water. This enables us to see the foundation of the masonry wall. In its present state the dam is not functional anymore.

When dams are repaired, trees growing on the dyke are removed, new earth, usually dug out of the basin, is added on top and is compacted with a small bulldozer. See picture of dam 195 (top right, taken at Pannekoek in 2007). In this case the earth has not been properly compacted. Earth has simply been piled on top. Very likely a loader was used instead of a bulldozer. In Dutch we say "prutswerk". This is what happens when accountants decide that the D4 is too old and loaders should be used.

The bottom right photo was taken Dam Kacho at Rio Magdalena.

Overflow structure/Spillway, locally called sakadó, of the dam at Jan Kok (6 Dec, 2016). There used to be a well downstream, which has been filled in and paved over by a road. The well was situated not far from where the picture is taken; it is marked on the old "Werbata" map of 1911-1915.

In the lower picture the much larger overflow structure/spillway of Dam Kacho at Klein Sta. Martha. The coconut trees in the background died during a previous period of drought.

The Dam Kacho at Klein Sta. Martha. This dam had been properly repaired about six months before this picture was taken; on November 27, 2016, using the D4 caterpillar bulldozer pictured on the right. This bulldozer is privately owned.

Caterpillar D4 is a light bulldozer, used for building dams. Although D5, D6 bulldozers and various loaders are also used, the D4 is considered the most suitable for this kind of work.

The Curaçao Caquetío Indians used a few watering holes in the main watercourses which were called "Xaguey". In colonial times a system of hand dug wells and dams was introduced.
The first dams and wells in the 17th, 18th and in the early 19th century were constructed with slave labor. In dry years the slaves would harvest salt in salt pans and in wet years they would work the fields to produce food (mostly Sorghum), with the excess harvest to be stored, to tide them over during the dry years. Around 1890 the first American type windmills were introduced on the island.

From 1908 on, there was a spurt of new dam-building activity (Ir. M.C. Fauel), and in the 1950's various larger dams were constructed to cover the increased use of water by the growing population. Ir. J. Beijering designed and constructed many of these newer dams (Plan Beijering, 1948). He personally supervised their construction and gave detailed instructions to the tractor drivers. These drivers were very proud to have served under his direction.
It was considered that the Caterpillar D4 bulldozer was most suitable for this work, the D6 being considered too heavy and loaders too light. Nowadays it is often not realized that the construction of earthen dams requires specialized knowledge (see below). During the heavy rains caused by tropical wave Thomas in 2010 a newer dam at Zapateer failed. This dam had been built to replace an older dam constructed by Beijering; the new dam was constructed somewhat downstream from

where the old dam had been located. Older dams downstream absorbed the extra flow of water and held. Housing developments have lead to the destruction of many dams. There are still a few large ones and about 800 smaller ones which are still functioning.

7. Proper construction of earthen dams with mechanized equipment

A trench is dug, along the length of the dam with approximately the width, the new dam will have. The depth of the trench depends on the height of the new dam. For a rather low dam the depth will be about a meter, for a higher dam it will be deeper. The trench is then filled in with clay soil; soil is brought in with either trucks or a scraper (also called Carrymore). While filling in the soil is compacted with a caterpillar (usually a Caterpillar D 4, see former page). Additional clay is brought in till the fill is about a meter or more above field level (depending on the height of the dam). It is again compacted with the caterpillar. Then the original fill, which was taken out while digging the trench, is applied to the sides of the dam, and everything is topped off with diabase soil till the desired height is attained. The ends of the dam are protected with stone walls and a stone masonry overflow (spillway) is constructed. The overflow is dimensioned to be able to disgorge 80 mm of rainfall/ hour falling in the catchment area feeding the dam; assuming the dam is already full. In some cases it is not necessary to construct a masonry overflow. For example where the dam is ending in a hill and the overflow runs over hard rock (for example the Soto dam and a few others as well).

8. Faha's

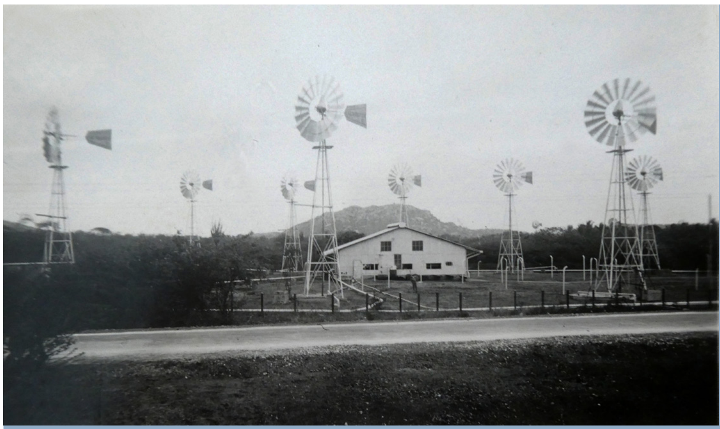
Footpath going up the Seru di Warawara (Warawara hill) at Santa Cruz, Curaçao, at the end of a long period of drought (24 May, 2014). In the picture a low dam running across the hill can be seen. Such structures are called "faha" meaning belt. Many were constructed in the past to conserve run-off rainwater, forcing the water into the ground, and also to a lesser extent to combat erosion.

9. Newer developments – Desalination and Reverse Osmosis

Desalination from seawater started in Curaçao in 1928. Through the years more and larger desalination plants were built (Multi-stage flash distillation, MSF). Since the early 1960's groundwater has not been used anymore in the drinking water system. Nowadays all drinking water is produced by Reverse Osmosis (RO) from seawater. The conductivity is now somewhat higher than it used to be in the past when the water was distilled. Since Curaçao groundwater contains high concentrations of silicates, which will poison the membranes, it is not practical to use reverse osmosis with groundwater.

10. Groundwater extraction for the refinery

When the refinery was built the KBPM (Koninklijke Bataafse Petroleum Maatschappij), later Koninklijke Shell or Royal Shell, bought several plantations which were used as water plantations to supply the refinery with fresh water for the refining process. Consequently the groundwater water level and quality at the plantations downstream of these water extraction plantations were negatively affected. Some went out of business. An elaborate pipeline and pumping system was built. In the first years of operation some fresh water was also imported with lighters (flat-bottomed barges) from Venezuela.



Picture on the left: Windmills at Julianadorp and pumping station and filtration plant. Picture was probably taken in the 1930's (Collection: Lendering family).

Picture on the right: The dam at Julianadorp. Windmills with extra large capacity and higher towers were used. The wind wheels seem to be either 10 or 12 ft diameter. The picture was probably taken in the 1950's; in the background the roofs of the newer houses, the first of which were built in 1947 are visible.

11. Surface waters and Groundwater

Studies of the run-off of surface waters (pers. comm. C.W. Winkel, Dept. of Agriculture and Fisheries, Curaçao) in the volcanic areas of Curaçao, have shown that when the rains start after a long dry season, the first surface run-off has a conductivity value of around 500 microSiemens (µS/cm). When it keeps raining, part of the water percolates through the soil and the conductivity in small rivulets increases, usually to up to 1500 µS/cm. When the rains then continue the salinity in such rivulets goes down again. In places where water has accumulated white salt and calcium deposits can be seen when shallow pools, rivulets and ponds dry out again and often dried out films of calcareous algae are left behind. Thus there must also be significant amounts of calcium present. In the rainy season, heavy rains cleanse the earth of large loads of salts, which are washed into the sea and thus rejuvenate the soils. All of this is observed in the volcanic non-limestone areas. In the limestone areas there is almost no surface run-off since limestone is much more porous.

If sufficient rain falls at the start of the rainy season, some of the water will percolate to the ground water level; this level rises and its salinity as measured in wells initially increases (sometimes by as much as 300 - 400 µS/cm), because of the heavy loads of salt that are washed down into the wells. Later on, during a good rainy season ground water level keeps rising and salinity in wells falls again, as groundwater flows to the sea sub-terraneaously and is replenished by lower salinity water.

The salinity levels of wells on the island in the volcanic zones (Curaçao lava formation) are lower in the centre of the island and increase toward the coast. A study by Abtmaier (1978) indicates the following: the wells in the central areas are usually below 2000 µS/cm, while those nearer to the coast increase to values above 4000 µS/cm.

There are three main reasons for this increase:

- The salt spray from the sea; part of which is washed down to the groundwater level by rains. This salt spray is stronger near the coast.

- Water used for irrigation increases in salinity due to evaporation, and then flows back into the ground.

- In areas near the sea there can be intrusion of sea water if the water level is lowered too much by excessive pumping.

There is a notable difference between the lava formation in the NW part of the island and the lava formation in the SE part of the island. In the NW part more than 55% of the wells are between 1500 and 2250 µS/cm (203 wells measured), while 13% are above 3000 µS/cm. In the

SE part of the island 45% of the wells are between 1500 and 2250 µS/cm (420 wells measured) while 20 % are above 3000 µS/cm. There is more influx of water from underground cesspits, which most houses use, into the groundwater, which will tend to lower salinity, but this part of the island, is also more exposed to salt spray and there is more irrigation with well water, both factors which tend to raise salinity. From the above it can be seen that the impact of the salt spray on the salinity in wells is considerable even though its effects are hard to quantify precisely, since other factors are also at work.

The difference in salinity in well waters between the narrow coastal zone and the volcanic areas is not absolute; it is more a difference in degree. It can also be noted that the conductivity of the water is quite high for horticulture. Salt sensitive crops cannot be cultivated. As explained earlier reverse osmosis of groundwater is not practical because of high concentrations of silicates.

Comparison of some conductivity values, values in (µS/cm)	
Location	**Values in (µS/cm)**
Rio Negro near Manaus	less than 40
Rio Ucayali	150
Zambezi	50-100
Volta river	60-170
Lake Victoria	98-145
Lake Malawi	210-235
Upper Congo river	44-108
Lake Tanganyika	550-600
Tap water in Curaçao	240 (distilled, before RO; salts were added to prevent corrosion of the pipes)
Drinkable water, less than 3000 (unsuitable for persons with high blood pressure or kidney problems)	

All pictures by the author except for historical pictures and where otherwise noted.

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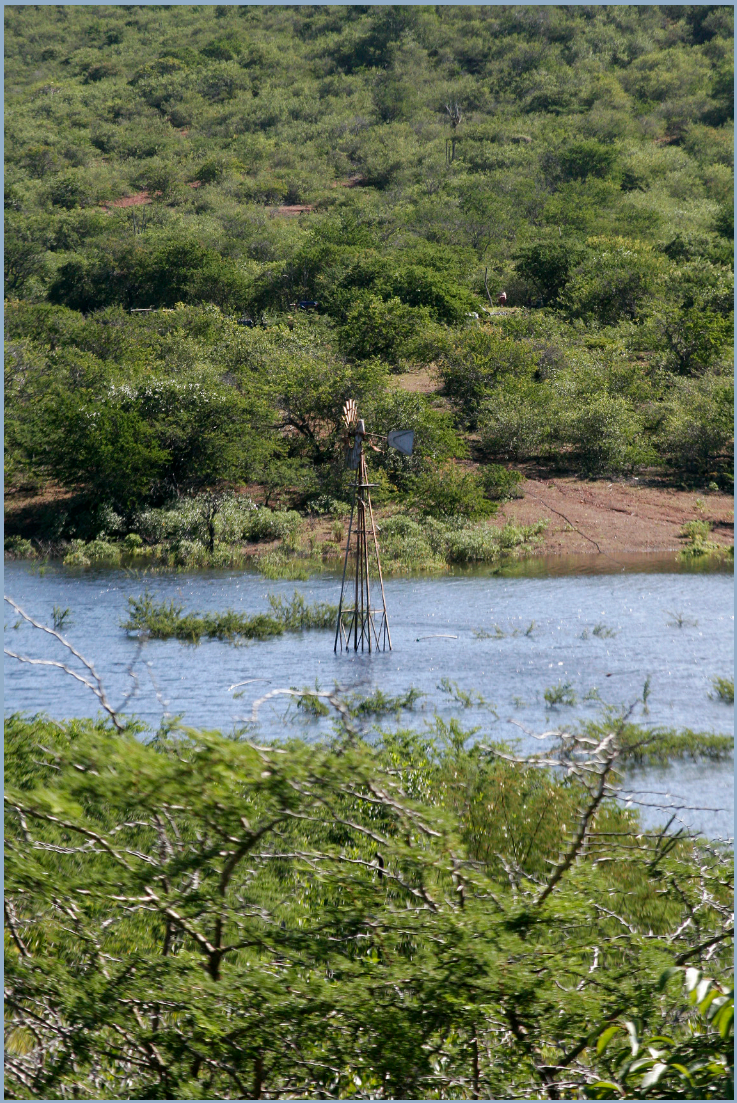
ANNEX

Some pictures which give an overview of dams of different sizes.

Dam Soto, the second largest one in Curaçao with a capacity of around 450.000 tons. Above on the 18th of September 2016, Below 30th of November 2008. In the picture about 2/3 of the surface area of the dam is visible. Picture Peter C. Winkel

Dam Soto, on the morning of the 27 th of November 2016, the dam was almost fully filled by heavy rains the day before; the water is still muddy. After a few days the mud will settle and the lake turns blue. The measuring scale cannot be seen in this picture, it is toward the right (south). The windmill (see on the right) cannot be seen either, it is to the left (north).

The picture of the windmill was taken on the 30th of November 2008. When the lake is full the water reaches about 1,20 meters below the platform of the windmill; the vanes are 8ft in diameter. The thorn trees in the water are Acacia tortuosa, locally called "wabi". These are fast-growing but cannot stand water logging very long. From their presence and size we can deduce that it had been quite a long time ago, at least a few years ago, that water had reached this high a level in the dam and/or that even if it did, the water must have infiltrated quite rapidly for these trees to be able to survive.




Opposite page top photo:
Dam at Dokterstuin, Kunuku Kalbas (27 nov, 2016). In this area there is a series of dams, one overflowing into the next. The trees are Calabash trees (Crescentia cujete); these can stand water logging and are often found in the basins of dams. Wabi trees (Acacia tortuosa) do not survive long periods of immersion.

Opposite page photo below:
This is an example of a fairly small dam at Pannekoek (22 Nov, 2016). This dam does not have masonry ends; the outflow (the sakadó) is dug into the side of the hill (in front of the electricity pole), where somewhat harder pillow lavas are found. The dam at Soto has a similar outflow. After heavy rains in the past, in 1970, the owner decided to deepen the outflow channel, thus lowering the capacity of the dam. He was afraid the dam would burst. During these rains a dam downstream of this one failed. The tree is a Lignum vitae locally called Wayaká (Guaiacum officinale), which does not stand water logging very well.

Current page top photo:
The dam at Malpaïs, locally called Lago disparsé, "the lake that has disappeared". Even though in this picture the lake has reappeared it is still called Lago disparsé (26 Nov, 2016). A fairly large dam & reservoir constructed by Shell to obtain water for the refinery. Nowadays water is not extracted anymore and it is a nature area with many water birds

This is a masonry dam, downstream from the dam Kacho, at Klein Sta. Martha. It is the last one before the water reaches the sea (Sta. Martha inner bay). It is a fairly long dam, which overflows fully, over its whole length during a good rainy season. This dam has an unusual feature, a door that could be opened or closed. According to a knowledgeable informant from this area, Mr. Alberto Wendell, this door was used in the past to let the first water after heavy rains escape to the sea. This water would be most heavily laden with salts. This dam is already marked on the old “Werbata” map of 1911-1915. A few more examples of sluice doors like this exist in Curaçao; but they are not very common.