Ground-water geology of the Gonaives Plain, Haiti 1/

by

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Abstract

The Gonaives Plain lies in northern Haiti at the head of the Gulf of Gonaives. Ground water in the plain is used widely for domestic and stock purposes but only to limited extent for irrigation. The future agricultural development of the plain will depend in large measure on the proper utilization of available ground-water supplies for irrigation.

The rocks in the region of the Gonaives Plain belong to the upper (?) Cretaceous series of the Cretaceous system, the Eocene and Oligocene series of the Tertiary system, and the Pleistocene and Recent series of the Quaternary system. The structural depression occupied by the Gonaives Plain was formed in post-Miocene time by the dislocation of Oligocene and older rocks along normal faults and by the tilting of the adjacent crustal blocks. The lower parts of the depression contain a Pleistocene and Recent alluvial fill deposited by streams tributary to the plain.

The upper (?) Cretaceous rocks include andesite and basalt lava flows locally intercalated with some beds of tuff and agglomerate. These rocks are generally dense and impervious but locally small springs rise from fractures and bedding planes or from weathered zones.

The Eocene rocks are hard, thin-bedded, cherty limestones with some beds of massive chalky limestone. Considerable ground water circulates through joints, bedding planes, and solution passages in these rocks giving rise to important springs such as Sources Madame Charles. These springs discharge at the rate of about 110 liters per second.

The Oligocene rocks include limestone, shaly limestone, limy sandstone, marl, and shale. The limestone beds contain solution passages and other openings and these may afford capacity for the circulation of ground water. However, no wells or springs in Oligocene rocks were observed during the present study.

The alluvial fill of the plain is composed of interbedded lenses of clay, silt, sand, and gravel. These deposits contain a zone of saturation whose upper limit is marked by a water table. The depth to the water table beneath the alluvial lowland of the plain ranges from less than one meter to about 20 meters. In most places in the plain the depth to water is less than 15 meters. Where present in the zone of saturation the coarse, well-sorted sand and gravel beds of the alluvium will probably yield moderate to large supplies of water to wells and infiltration galleries. The individual yields of existing wells range from a few liters to about 60 liters per second.

The most favorable part of the plain for ground-water prospecting and development lies 5 to 10 kilometers northeast of Gonaives. In this area yields of 10 to 50 liters per second could be obtained from the alluvium in simple wells drilled to depths of about 35 to 45 meters. Additional information on the yield and physical character of aquifers in the alluvium would be provided by test wells drilled to depths of 40 to 60 meters.

Introduction

The Gonaives Plain is located in northern Haiti at the head of the Gulf of Gonaives. (Fig. 1). The principal city of the plain is Gonaives, capital of the Department of Artibonite and 180 kilometers by road north-northwest of Port-au-Prince.

A general study of the geology and ground-water conditions of the plain was made by the writers in February 1949. This work was part of a larger program of ground-water studies in Haiti by the Institute of Inter-American Affairs in cooperation with the U. S. Geological Survey. The work was done under the general direction of Mr. W. Alan Laflin, chief-of-party of the Food Supply Division of the Institute in Haiti.

At present irrigation is practiced in the Gonaives Plain and its tributary valleys by diversions from streams. During the dry season the flow of these streams is usually sufficient to cover much of the valley areas, but the plain itself receives only sporadic irrigation or none at all. The principal object of the present study was to investigate the occurrence of ground water in the plain and the feasibility of developing water supplies from wells or other structures for irrigation.

Precipitation

The Gonaives Plain receives rain principally from the northeast trade winds which reach the north coast of Haiti laden with moisture. However, in passing over the high mountains of the Massif du Nord condensation occurs and most of the moisture is precipitated on the northeast slopes of these mountains. On reaching the Gonaives Plain to the southwest of the mountains, the winds are largely deprived of moisture. Consequently the plain receives very little rain and is perhaps the driest lowland region in Haiti. As based on 42 years of record the mean monthly and annual rainfall at Gonaives is as follows:

Rainfall at Gonaives, in Millimeters

January	4.4	July	74.0
February	14.0	August	89.3
March	15.2	September	85.2
April	29.8	October	60.0
May	82.8	November	23.1
June	91.5	December	10.8

Year-----520.1

These data suggest that the marked concentration of rainfall in two wet seasons characteristic of most of Haiti does not occur in the Gonaives region. Rather there seems to be only one long wet season lasting from May through October with a short break in July. In the 6-months dry season from November through April the total rainfall averages only 97.3 millimeters at Gonaives. During the same period the northeast trade winds blow with greater intensity and constancy than in the wet season in the Gonaives Plain. Consequently evaporation is increased and the light precipitation that occurs is ineffective in maintaining soil moisture in the plain. Irrigation is therefore necessary for crops during the dry season and is desirable for optimum plant growth during the wet season.

The rainfall at Gonaives is probably representative for most of the lowland area of the plain. However, the bordering mountain slopes may receive half again to twice as much rainfall as the plain. To large extent the amount of rainfall received by the mountain slopes depends on their elevation and exposure to the northeast trade winds.

Topography and drainage

The Gonaives Plain is alluvial lowland of approximately triangular outline (Fig. 1). At its southern limit it attains a maximum width of about 11 kilometers from east to west. To the north the width of the plain gradually decreases to about 1-1/2 kilometers near the junction of the Riviere d'Ennery with the Riviere La Branle. The plain has a maximum length of about 13 kilometers from north to south.

Along its entire western margin the plain is bordered by foothills and spurs of the Montagnes de Terre Neuve. The highest point in these mountains near the plain is Morne Biennac whose elevation in 325 meters above sea level. The crest of this mountain is located 3 kilometers north of Gonaives.

To the south of the valley of the Riviere d'Ennery the plain is bordered along its eastern margin by long linear ridges which are spurs of the Montagnes Noires. Bayonnais Ridge lying between the valley of the Riviere des Bayonnais and the plain is perhaps the most prominent of these. It attains a maximum elevation of about 400 meters above sea level. On the northeast side of the Bayonnais Valley is a second ridge which extends northward beyond the point of Bayonnais Ridge to the Ennery Valley. This ridge reaches elevations of about 500 to 600 meters. Near its southern limit the Gonaives Plain is split by the northern tip of Morne Grammont. This ridge is a large isolated outlier of the Montagnes Noires. Its maximum elevation is 406 meters above sea level.

North of the Ennery Valley and east of the valley of the Riviere La Branle are the mountains of the Massif du Nord which border the plain on the northeast. The highest point in these mountains near the plain is Morne Deux Mamelles whose elevation is 784 meters above sea level.

The surface of the Gonaives Plain rises evenly from the sea at Gonaives Bay to an elevation of about 120 meters at its northern limit, near the junction of the valleys of the Riviere La Branle and the Riviere d'Ennery. At the entrance of the alluvial valley of the Riviere Bassin the plain is about 80 meters above sea level and about the same at the entrance of the Bayonnais Valley. South of Gonaives and west of Morne Grammont the Gonaives Plain is contiguous with the Artibonite Plain. East of Morne Grammont the Gonaives Plain merges imperceptibly with the Savane Desolee, a small alluvial basin which extends on southeastward for several kilometers. Where the plain merges with this basin the general elevation is about 20 meters above sea level. Near the sea the plain is low and barrely dissected. Inland the slope of the plain increases gradually and the principal streams are incised to depths of 2 to 5 meters below its surface.

The trunk stream of the Gonaives Plain is the Riviere La Quinte which is formed by the confluence of the Riviere La Branle and the Riviere d'Ennery. Farther south in the central part of the plain the Riviere La Quinte is joined by the Rivieres Bassin and des Bayonnais.

The Riviere La Quinte is an intermittent stream through most of its length. It carries water only in the rainy season and into the first part of the dry season. However, in the lower 8 kilometers of the stream there is a small perennial flow that persists through the dry season. This flow is sustained principally by the discharge of Sources Bongry (no. 2) located along the channel of the stream about one kilometer upstream from the Quinte bridge on the Gonaives-St.Marc road. On February 16, 1949 the flow near the bridge was estimated at about 90 liters per second. The flow was measured by the Service des Eaux et Forets on February 17, 1937 at 130 liters per second. These discharges represent the order of magnitude of the stream flow in the middle or latter part of the dry season. The Riviere La Quinte was entirely dry upstream from Sources Bongry to the Riviere d'Ennery during January and February 1949. In the rainy season the Riviere La Quinte may carry discharges of several cubic meters per second. A flow of 6/74 cubic meters per second was measured on November 12, 1924 by the Service d'Irrigation, Dept. des Travaux Publics at the Mapou Chevalier bridge near Les Poteaux.

In the lower reaches of their alluvial valleys and in their courses across the Gonaives Plain all of the tributary streams of the Riviere La Quinte are intermittent. They carry water only in the rainy season and during the first part of the dry season. In their upper and middle courses the tributary streams are perennial and carry small dry-season flows ranging from a few ten to a few hundred liters per second. This water is all diverted for irrigation in the alluvial valleys of these streams.

Geology

General features

The rocks that crop out in and adjacent to the Gonaives Plain belong to the upper (?) Cretaceous series of the Cretaceous system, the Eocene and Oligocene series of the Tertiary system, and the Pleistocene and Recent series of the Quaternary system. The general geology of the Gonaives Plain and of the adjacent mountain borders is shown in Figure 2.

The rocks of the Gonaives region were disturbed at a number of different geologic times by orogenic movements. According to Woodring, Brown, and Burbank[2] three principal periods of folding probably affected the rocks of the region--one near the end of Cretaceous time, one at the end of Eocene time, and another near the end of Miocene time. Each successive movement involved all older rocks.

2/ Woodring, Wendell P., Brown, John S., Burbank, Wilbur S.; Geology of the Republic of Haiti: Republic of Haiti, Dept. of Public Works, Geological Survey of the Republic of Haiti, p.631, Port-au-Prince, 1924.

The structural depression occuppied by the Gonaives Plain probably originated in post-Miocene[3] time by the tilting of crustal blocks along

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[3] Op. cit., p.336

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normal faults. This depression is the southern extension of the Trois Rivieres trough, a narrow graben that trends north-northwest from the north end of the Gonaives Plain to the north coast of Haiti near Port-de-Paix. The graben is 5 to 8 kilometers wide and about 50 kilometers long. Along most of its eastern and western flanks it is bounded by normal high-angle faults. The fault line which limits the eastern side of the graben extends south into the Gonaives region and dies out a few kilometers south of the Ennery Valley. Farther south are two faults which lie en echelon with that of the east side of the graben. One of these is on the southwest side of Bayonnais Ridge and the other is along the northeast flank of the Bayonnais Valley. (See Fig.2) Both of these are apparently high-angle normal faults dipping southwest and along which the northeast block has been uplifted and tilted to the northeast. A similar and parallel normal fault probably lies along the southwest side of the Morne Grammont block which is also tilted to the northeast[4]. All three

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[4] Op. cit., p.336.

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of these faults die out to the southeast and pass beneath the alluvial fill of the Gonaives Plain to the northwest.

The structural depression of the Gonaives Plain is directly underlain by an extensive alluvial fill deposited by streams that enter the plain from adjacent mountain areas. Most of this fill was probably laid down in Pleistocene and Recent time. Evidently there were two principal bycles of filling-an earlier cycle of probable Pleistocene age and a later cycle in Recent time. Following Pleistocene alluviation the streams cut down in their deposits to a level considerably below the present surface of the plain. During the ensuing cycle of renewed alluviation in Recent time, the Pleistocene deposits in the lower parts of the plain were covered by the younger deposits. However, in protected recesses along the borders of the plain the Pleistocene deposits were left as dissected alluvial fans or terraces which lie 5 to 20 meters above the present surface of the Recent alluvium.

Geologic formations and their water-bearing properties

Cretaceous volcanic rocks

The oldest rocks in the Gonaives region are of probable upper(?) Cretaceous age and are of extrusive igneous origin. They include an extensive sequence of lavas with some pyroclastics that may attain a thickness of 1,000 meters 5/ or more in this region. Most of these

5/ Op. cit., p. 265.

rocks cropping out in the borders of the Gonaives Plain appear to be andesites although basalts also occur. Locally beds of indurated agglomerate or tuff are intercalated with the lava flows. The areas of outcrop of upper(?) Cretaceous rocks observed during the present study are shown in Figure 2. However, outcrops of upper(?) Cretaceous rocks not observed may be present in areas mapped as Eocene especially along the southeastern margin of the plain and along the eastern border of the Savane Desolee. Hornblende andesite 6/ crops out in a cut of

6/ Op. cit., p. 278.

the abandoned Gonaives-Ennery railroad 4 kilometers airline northeast of Les Poteaux. At this point the andesite is in fault contact with basalt which is younger than the andesite although also of upper(?) Cretaceous age. Essexite 7/, a basic igneous rock of diabasic texture,

7/ Op. cit., p. 280.

was also observed near the base of a prominent conical knoll about one kilometer northeast of Les Poteaux.

The upper(?) Cretaceous andesites and basalts with the intercalated pyroclastics are hard dense rocks with few openings through which water may circulate. Locally small springs rise from fractures and bedding planes or from weathered zones where the rocks crop out at the surface. However, generally the rocks appear to form an impervious basement on which younger formations rest.

Eocene limestone

Resting unconformably on an ancient erosion surface cut in folded upper(?) Cretaceous volcanics is a thick series of marine limestones of upper Eocene age. These rocks form most of the hills and ridges along the eastern border of the plain and Morne Grammont (Fig.2). In most places the upper Eocene rocks are hard, thin-bedded, gray and white cherty limestones. Locally, however, massive chalky facies occur. The characteristic upper Eocene form Dictyoconus puilboreauensis nannoides Woodring was collected[8] at the north end of Morne Grammont and on the southwest slope of Morne Bienac. It was also found by the writers in limestones at the north end of Bayonnais Ridge.

[8] Op. cit., p. 144.

The upper Eocene limestones are moderately soluble in water weakly charged with carbonic acid. Commonly in outcrops the rock is pitted and fretted by solution. In many places underground percolating waters have enlarged the joints and bedding planes of the rock by solution. These openings afford passages for circulating ground water. Where present in the zone of saturation the limestones would probably yield moderate to large quantities of water to wells. However, in the hills bordering the plain the upper Eocene limestones are considerably dissected and are probably rather thoroughly drained at least to the level of the surface drainage of the region.

Sources Madame Charles, No. 1, is a notable group of springs that issue from upper Eocene limestones. These springs are about 4 kilometers northeast of Les Poteaux at the edge of the Ennery Valley. There are several spring heads in the group located on a line about 100 meters long. The springs issue from bedding planes and joints in thin-bedded white limestones. The spring line is situated at the base of a bluff on the west side of the alluvial valley of the Riviere d'Ennery. The total discharge of the springs was measured at 110 liters per second by the Service des Eaux et Forets on February 18, 1937. When visited by the writers in February 1949 the flow was approximately the same. The temperature of the water is 26°C.

Oligocene limestone

Rocks considered to be of upper Oligocene age form most of the western border of the Gonaives Plain. They also appear along the southwest base of the Massif du Nord where they are in fault contact with Cretaceous or Eocene rocks. Along the southeastern flank of Morne Bienac near Gonaives some rocks shown in Figure 2 as Oligocene may be Eocene. Characteristic upper Eocene fossils were collected[9] at a number

9/ Idem, p. 144.

of localities on the southwest slope of this mountain. However, the upper Oligocene foraminifera Miogypsina antillea (Cushman) and Lepidocyclina giraudi R. Douville were found[10] on a low hill about 4 kilometers north-

10/ Op. cit., p. 156.

east of Gonaives near the Gonaives-Port-de-Paix road. The upper Oligocene rocks include thin or massively bedded yellowish-grey marine limestone, shaly limestone, limy sandstone, marl, and green shale.

The limestones of the upper Oligocene series show solution features similar to those of the upper Eocene limestones. Surface outcrops are commonly roughened by solution, and in many places joints and bedding planes have been enlarged by solution of percolating waters. These openings may afford considerable capacity for the circulation and storage of ground water. Because the limestones are interbedded with impervious shales and marls, the over-all permeability of the upper Oligocene series may not be as great as that of the upper Eocene limestones. No wells or springs in upper Oligocene rocks were observed during the present study.

Older alluvium

Pleistocene stream deposits crop out in terrace remnants and dissected alluvial fans along the borders (Fig.2) of the Gonaives Plain and probably underlie Recent alluvium beneath much of the lowland. In the outcrop areas the Pleistocene deposits are essentially coarse-textured poorly-sorted gravels with considerable admixture of silt and find sand. The pebbles and cobbles in the gravels are mostly of limestone although weathered basalt, andesite, and diorite pebbles occur in scattered instances. At the surface the Pleistocene deposits are commonly capped by caliche, and at least the near-surface parts of the deposits are indurated by a secondary cementation of calcium carbonate. Beneath the lowland area of the plain the Pleistocene deposits are very similar in physical character to the overlying Recent alluvium except that they are somewhat more consolidated.

Where consolidated or indurated by cementation the Pleistocene deposits may have lost a considerable part of their original permeability. In other respects the water-bearing characteristics of the Pleistocene deposits are similar to those of the Recent alluvium.

Younger alluvium

Recent alluvium directly underlies the surface of the Gonaives Plain as well as its tributary alluvial valleys (Fig. 2). The alluvium is made up of intercalated lenses of unconsolidated clay, silt, sand, and gravel. It is coarsest textured in the alluvial valleys and in the areas where the valleys merge with the plain. In these zones the alluvium is principally gravel and sand with relatively little clay and silt. In the central part of the plain clay, silt, sand and gravel appear to be present in about equal proportions. The Recent alluvium in the lower parts of the plain near the sea is largely clay, silt, and sand with only a little gravel.

The clay and silt facies of the Recent alluvium have very low permeability and hence have little capacity to yield water to wells or springs. However, the gravel and sand facies are moderately to highly permeable. To a large degree the permeability of the sands and gravels is dependent on the extent of their sorting by running water. The coarsest and best sorted gravels were laid down in the channels of the larger streams. The fine-textured clays, silts, and fine sands were deposited from quiet waters in areas adjacent to the stream channels during floods.

Shallow dug wells indicate that within 15 to 20 meters of the surface the Recent alluvium is coarsest textured and best-sorted in that part of the plain lying between the 30 and 100-meter water-table contours shown in Figure 2. It is believed that in this part of the plain the Recent alluvium is generally more permeable than elsewhere. The general characteristics of ground water in the alluvium are discussed beyond.

Ground water in the alluvium

The most important ground-water body in the Gonaives Plain occurs in Recent alluvial deposits and possibly in similar underlying Pleistocene deposits. This ground-water body is sustained and recharged, 1) by infiltration from streams that enter the plain, 2) by seepage from irrigation in valleys tributary to the plain, 3) by the underflow of the alluvial valleys of the larger streams, 4) by direct penetration from precipitation on the surface of the plain, and possibly 5) by underground leakage from water-bearing Eocene or Oligocene rocks. The principal recharge to the ground-water body probably occurs during the rainy season when the streams are in flood and the precipitation is greatest on the plain.

The upper limit of the zone of saturation in the alluvium of the plain is marked by a water table whose position, shape, and slope in February 1949 are shown in figure 2 by means of 10-meter contours referred to sea level. In general the water table slopes southwestward from the north end of the plain to Gonaives Bay with a gradient approximately parallel to that of the land surface. Likewise in each alluvial valley tributary to the plain the water table slopes downvalley until it merges with the water table at the plain.

Water received in the zone of saturation by infiltration from the surface or from other sources moves down-gradient along the slope of the water table. Water is discharged from the zone of saturation, 1) by evaporation or by transpiration of plants where the water table is at or near the surface, 2) by springs above sea level, and 3) by submarine springs.

Evaporation from the zone of saturation occurs where the water table is at the surface or the capillary fringe extends to the surface. At least in the dry season such evaporation appears to be concentrated principally in that area of the plain lying less than 5 meters above sea level. During the wet season with the rise of the water table the area of evaporation extends to other parts of the plain. Ground-water discharge by transpiration occurs wherever the roots of phreatophytic plants reach the water table or the capillary fringe. Considerable parts of the central and coastal areas of the plain are overgrown with thickets of bayahonde, a thorny leguminous tree resembling American mesquite. These trees together with other phreatophytic plants evidently transpire large quantities of water from the zone of saturation especially during the dry season.

Ground-water discharge by springs takes place chiefly along the channels of the Riviere La Quinte and its tributaries. Such springs occur where the water table in the alluvium is intersected by a stream channel or other depressions. With the exception of Sources Bongry (No.2) all such springs are of temporary character. They flow only during the rainy season and the first part of the dry season when the water table rises and intersects the stream channels. When the water table declines in the dry season the springs go dry. A typical example is Source Marchand (No. 55) in the channel of the Riviere La Quinte. This spring is reported to flow a few tens of liters per second in the rainy season. However, when visited by the writers on February 16, 1949 the spring was not flowing and the water table was about 2.3 meter below the stream channel at the spring head. Evidently in very rainy years the flow of this spring may persist through most if not all of the dry season. On February 18, 1937 apparently following an exceptionally rainy wet season the flow of the spring was measured at 20 liters per second by the Service des Eaux & Forets.

Sources Bongry,(No. 2) are apparently the only important perennial springs that rise from the alluvium of the Gonaives Plain. There are three principal spring heads in the group located along the channel of the Riviere La Quinte about one kilometer upstream from the Quinte bridge of the Gonaives-St. Marc road. The springs issue from sand and gravel in small recesses along the banks of the stream and about 2 meters below the general land surface. The total flow of the springs on February 16, 1949 near the Quinte bridge was estimated at 90 liters per second. At the same place the flow was measured by the service des Eaux et Forets at 130 liters per second on February 17, 1937. These discharges represent the magnitude of the dry-season flow of the springs. The wet-season flow is reported to be much greater.

Formerly there were a number of perennial springs and swampy tracts in the vicinity of Gonaives and in the area 1 to 2 kilometers northeast of the city. These are now controlled by two systems of open drainage ditches constructed by the Service Cooperatif Inter-Americain de la Sante Publique. One of these systems empties into Gonaives Bay just north of the city. Its total discharge on February 17, 1949 was estimated by the writers at about 79 liters per second. The second system passes through the city and flows into Gonaives harbor. The discharge was approximately 25 liters per second on February 17. The discharges of both of these drainage systems increases markedly with the rise of the water table in the wet season.

A general seepage from the zone of saturation also occurs in the tidal flats along the shore of Gonaives Bay. Ground-water discharge may also occur in submarine springs near the edge of Gonaives Bay.

During the present study data on the depth to water and the character of the water-bearing materials in the alluvium were obtained for some 60 typical wells scattered over the Gonaives Plain. The depths to water in individual wells in February 1949 are shown in Figure 2. Practically all of these wells tap water in unconsolidated or semi-consolidated sand and/or gravel in the alluvium. The depth to water measured in these wells ranges from 0.30 meters to 17.60 meters below the land surface. The water table in the alluvium of the Gonaives Plain is practically everywhere within 20 meters of the land surface and generally is less than 15 meters below the surface. The deepest water levels occur along the margins of the plain where the surface of the alluvium is high.

The water level in wells in the alluvium fluctuates seasonally-being highest during the latter part of the rainy season and lowest near the end of the dry season. These changes appear to be greatest in wells situated near the Riviere La Quinte and its principal tributaries. For example in well 3, the water level has been observed to move through a range of about 4 meters during the year. In wells more distant from the stream channels comparable changes in water level amount to about 0.75 to 2 meters during the year. These fluctuations in the water table reflect seasonal changes in the amount of water stored in the zone of saturation. In the rainy season recharge exceeds discharge and the water table rises, but in the dry season discharge exceeds recharge and the water table declines.

The ground water at least in the shallow water-bearing beds of the alluvium is generally potable and of good chemical quality. However, in a small area extending inland 1 to 2 kilometers from Gonaives Bay the shallow ground water is generally brackish. The inland limit of the brackish ground water is shown in Figure 2. The shallow ground water in the area east of Morne Grammont is also brackish in places.

Ground water in bedrock formations

The alluvium of the Gonaives Plain probably rests on a bedrock floor of Eocene and Oligocene rocks and in places on Cretaceous rocks. Sufficient data were not available for the present study to ascertain definitely the water-bearing character of these rocks or the presence or absence of productive aquifers since none of the existing wells in the plain penetrates through the alluvium. The Cretaceous rocks are manifestly unfavorable, but some of the cavernous Oligocene and Eocene limestones should prove to be good aquifers where present in the zone of saturation.

It is reported that about 1940-42, the J. G. White Engineering Company drilled a number of test wells in the Gonaives Plain to depths ranging from about 100 to 200 meters. However, the well logs and other hydrologic data from this drilling have been either lost or misplaced and were not available for the present study. According to a report of Mr. Eddy F. Borjesson, a former employee of the company, the test wells encountered either improductive strata or salt-water aquifers in the bedrock formations. Moreover, the water-bearing beds in the alluvium encountered by the test wells were considered by the driller to be more productive than any found in the underlying bedrock.

Utilization of ground water

The ground water in the alluvium of the Gonaives Plain has been developed extensively for domestic and stock purposes and to limited extent for irrigation. It is estimated that there may be 200 or more shallow dug wells used for stock and domestic purposes in the plain. The wells shown in Figure 2 are typical. Seldom do these dug wells extend more than one of 2 meters below the lowest stage of the water table. Most of the wells are open and uncurbed and hence are readily subject o pollution by surface drainage and seepage. None of the dug domestic or stock wells is equipped with a mechanical pump. A simple hand line with bucket is generally used for drawing up water.

There are apparently only two existing drilled wells in the plain. Well 1 is located about 3-1/2 kilometers northeast of Gonaives on the Geronville plantation. The well is reported to have a depth of about 25 meters - all of which is in allumium. The principal water-bearing bed is in sand and gravel. The well is equipped with a 6-inch Johnson turbine pump and yields about 15 liters per second. The static and pumping water levels are not known because the well head is sealed. The water has a temperature of 290°C. and has a very good taste. The well was drilled by the J. G. White Co. about 1941. It has since been used from time to time for irrigation although at present it is idle.

Well 2 at the Mapou Chevalier bridge over the Riviere La Quinte is located about 7-1/2 kilometers northeast of Gonaives. The well has a 14-inch casing which is now capped at the surface by a steel plate. It is reported that the well is about 25 meters deep and that the principal water-bearing stratum is in gravel near the bottom. The static water level is reportedly about one meter below the surface. The well was also drilled by the J. G. White Co. in 1941. At the time it was put down a yield of about 60 liters per second was obtained with a pump. However, the well was never put into use.

Ground water for irrigation has been developed from shallow dug wells and a trench at three places (wells 19, 20 and 29) on the Bayard property about 2-1/2 kilometers east of Gonaives. At site 19 are 3 dug uncurbed wells 4.50 to 4/60 meters deep and spaced in line about 4 meters apart. The wells are interconnected at the bottom with a 6-inch pipe line and are pumped as a unit. The static water level was 2.30 meters below the surface when the installation was visited in February 1949. A similar battery of wells has been constructed at site 29. Here are 5 dug wells which are each 2 meters in diameter and spaced on line 4 meters apart. The wells range from 3.40 to 4.10 meters deep and the static water level is 2.00 meters below the land surface. The wells are interconnected by a 6-inch pipe at the bottom. At site 20 a rectangular uncurbed pit with dimensions of 3 x 4 meters has been dug to a depth of 4.50 meters. The static water level in the pit was 2.70 meters below the surface when observed. The pit is connected to an open trench 3 meters deep and about 200 meters long. When the water level in the pit is drawn down by pumping the trench discharges into the pit at about 3 liters per second. The sustained capacity of the pit and trench during pumping does not appear to be much more than about 5 liters per second. All of the three installations, that is, wells 19, 20 and 29 are pumped with the same portable 4-inch centrifugal pump which is powered by a gasoline motor. The yields obtained at wells 19 and 29 were not observed.

The pits and trench at all three installations are dug in relatively tight silt or clay containing only a few thin streaks of water-bearing sand. The pit at No. 20 evidently enters a few centimeters into water-bearing sand and gravel at the bottom, but the penetration is not sufficient to develop the stratum. The yields now obtained at all three installations could be increased by deepening the wells until they penetrate one or more beds of productive water-bearing sand and/or gravel.

Conclusions

With the exception of the few wells previously described ground water in the Gonaives Plain is not utilized for irrigation. The results of the present study indicate that ground water in quantity sufficient for irrigation can be obtained from the alluvium by gravity from infiltration galleries or developed springs and by pumping from drilled or dug wells.

Infiltration galleries and developed springs

The water table in the alluvium of the Gonaives Plain has a relatively steep gradient especially in the northern part of the plain. This condition suggests the possibility of developing ground water for irrigation by gravity from infiltration galleries. The most favorable sites for the construction of such galleries would be in those places where the water table is near the surface and where the near-surface water-bearing strata are permeable. The stretch of the channel of the Riviere La Quinte between Source Marchand (No.55) and the Mapou Chevalier bridge is favorable for the construction of such a gallery. Moreover, the stream channel at Source Marchand itself seems to be a good location. Here the water table at its low or dry-season lies within about one to 2 meters of the surface of the channel. The water-bearing material at this point is coarse permeable gravel. An infiltration gallery could be constructed here 1) by trenching to a depth of a few meters below the low or dry-season stage of the water table, and 2) by laying perforated concrete or metal piping in the bottom of the trench and back filling. Water collected by the gallery could be led by gravity from the perforated pipe section of the trench into a similar blank pipe and brought up to the general land surface of the plain on a gradient somewhat flatter than that of the water table. Once at the land surface the water could be led to irrigated lands through open ditches. It is estimated that a gravity supply of the order of a few tens of liters per second could be developed in this manner by an infiltration gallery perhaps 50 to 100 meters long. Of course such a gallery would have to be constructed in the dry season to avoid damage from wet-season floods in the river.

The only permanent springs in the plain susceptible of development are Sources Bongry (No. 2). The dry-season flow of the stream fed by these springs is used only for domestic and stock water which could also be readily obtained from nearby dug wells. The normal dry-season flow of approximately 90 to 130 liters per second is now essentially wasted. By means of a simple diversion dam about 2 meters high this water could be diverted into ditches for irrigation. Such a dam could be constructed at any suitable location downstream from the principal spring heads. The dry-season flow of the stream would probably be considerably increased by cleaning the spring heads of aquatic vegetation and other debris.

Drilled wells

The two existing drilled wells (Nos. 1 and 2) in the Gonaives Plain indicate that water supplies in quantity sufficient for irrigation can be developed from wells of moderate depth drilled into the alluvium. Well 1 yields about 15 liters per second and well 2 has reportedly produced about 60 liters per second. Both wells are approximately 25 meters deep.

It is believed that yields of the same order of magnitude could be obtained from properly constructed wells of comparable depth in other parts of the plain. However, the areas lying 1)between the 10-meter water-table contour (Fig. 2) and Gonaives Bay and 2) east and east-northeast of Morne Cremmont may not generally be favorable. In these areas the alluvium is probably either fine-textured and of low permeability or the ground water is of poor chemical quality. The present geologic study indicates that the area lying between the 30 and 100-meter contours (Fig. 2) is the most favorable zone in the plain for ground water development by drilled wells. In this area the alluvium contains one or more beds of permeable water-bearing gravel and/or sand. It is believed that yields of 10 to 50 liters per second could be obtained by pumping from simple wells drilled to depths of about 35 to 45 meters in this area.

Before large production wells are put down some additional test drilling would be desirable to determine the position, thickness and physical character of the aquifers and the chemical quality of the water at different places in the plain. The data so obtained should be carefully tabulated and preserved for reference. Suggested locations for test drilling are in the general vicinity of domestic wells 35,40, 47, and 58 (Fig. 2). Test wells drilled to depths of about 40 to 60 meters at these locations should be adequate to prove the water-bearing characteristics of aquifers in the alluvium. Drilling to greater depth does not appear worthwhile in view of the negative results obtained by the J. G. White Co. by drilling into the bedrock formations.

Dug Wells

The economic resources of the average individual farmer in the Gonaives Plain are far from sufficient to cover the cost of a deep drilled well equipped with power pump or even the costs of operation and maintenance of the pump. This type of ground-water development appears limited to cooperatives or to large land owners.

The average individual holding in the plain is only a few hectares. At least considerable parts of these lands could be irrigated at no great expense by windmill pumps placed over shallow dug wells. Water sufficient in quantity to sustain the capacity of a windmill could be obtained readily from dug wells less than 20 meters deep in the alluvium. The current cost for digging an open, uncurbed well in the plain ranges from about 60 to 80 cents per meter. Moreover, in the dry season when water is most needed there is an almost constant movement of the northeast trade winds across the plain. Thus sufficient motive force is provided for windmills. If sufficient surface storage capacity is provided for the water pumped, 1 to 2 hectares of land could be readily irrigated from one windmill. It is believed that experimentation in irrigation from windmills would be worthwhile at farmers' cooperatives such as that at Dubedou.

U. S. Geological Survey
Washington, D. C.
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TABLE I

Data on Typical Wells of the Gonaives Plain, Haiti

February 1949

Map No.	Depth (Meters)	Depth to Water Below Land Surface (Meters)	Character of Water-Bearing Material	Remarks
1	25 ±			Drilled. Well yields 15 lts./sec. with turbine pump. Water temperature 29° C. At Deronville property.
2	25 ±	1 ±	Gravel	Drilled in 1941 by J. G. White Co., 14-inch casing. At Mapou Chevalier.
3	5.65	5.60	Coarse well-rounded gravel with sand.	Dug. Water rises to within 1-2 m. of land surface during floods of Rivière La Quinte.
4	1.85	1.05	Unconsolidated sand	Dug. Concrete curb 2m. square. Water rises to about 0.35 M. below surface in rainy season.
5	2.05	1.75	do do	Dug. Uncurbed. 1 m. diameter. Water level rises about 0.5 M. in rainy season.
6	5.10	4.80	Clayey sand	Dug. Uncurbed. Water level rises about 1.0 M. in rainy season.
7	4.15	3.20	" "	Dug. Uncurbed. Good Water.
8	3.20	2.70	Firm sand	Dug. Uncurbed. Brackish water.
9	3.80	3.20	Sand with gravel	Dug. Uncurbed. Good water
10	3.80	3.35	Sand	Dug. Uncurbed. Water somewhat brackish.

TABLE I. (Cont.)

Map No.	Depth (Meters)	Depth to Water Below Land Surface (Meters)	Character of Water-Bearing Material	Remarks
11	1.45	1.15	Soft sand	Dug. Uncurbed. Water rises to within 0.5 M. of surface in rainy season.
12	1.90	1.00	" "	Dug. Brick curb.
13	1.40	1.20	Unconsolidated gravel	Dug. Uncurbed. Water level rises 0.20 to 0.25 M. in rainy season. Good water.
14	3.50	3.40	Clayey sand	Dug. Uncurbed.
15	4.10	3.90	Gravel with sand	Dug. Uncurbed. Good water
16	3.20	2.50	Clayey sand	" " " "
17	4.30	3.50	Sand	" " " "
18	2.00	1.90	"	" " " "
19	4.50 - 4.60	2.30	Clayey sand	3 dug wells. Uncurbed. Each 2 m. in diameter and 4 m. apart. 6-inch pipes connect wells at bottom.
20	4.50	2.70	" "	Dug. Uncurbed. 3 x 4 m. connected to drain about 200 m. long cut about 0.3 M. below water table. Temp. 25° C.
21	10.00	9.20	Gravel	Dug. Uncurbed. Brackish water
22	10.10	8.90	"	Dug. Uncurbed. Good water
23	14.00	Dry		Dug. Uncurbed.

TABLE I (Cont.)

Map No.	Depth (Meters)	Depth to Water Below Land Surface (Meters)	Character of Water-Bearing Material	Remarks
24	9.50	9.50		Dug. Uncurbed. Good water
25	12.20	11.80	Sand with gravel	" " " "
26	6.50	6.40	Gravel	" " " "
27	2.10	2.00		" " " "
28	2.60	2.40	Sand with clay	" " " "
29	3.40 - 4.00	1.90 - 2.00	" " "	5 dug wells. Uncurbed. Good water. Each 2 M. in diameter and 4 M. apart 6-inch pipes connect wells at bottom. Pumped with 4-inch mobile centrifugal sump pump.
30	7.60	5.60		Dug. Masonry curb. Good water
31	6.90	5.00		" " " " "
32	6.00	Dry		Dug. Uncurbed. Water rises in well during rainy season.
33	4.50	4.00	Sandy clay	Dug. Uncurbed. Good water
34	5.20	5.00		" " " "
35	6.70	6.60	Coarse well-rounded gravel	Dug. Uncurbed. Water level rises about 2 M. or more in rainy season.
36	2.90	2.60	Sand with clay	Dug. Uncurbed. Water slightly brackish

TABLE I (Cont.)

Map No.	Depth (Meters)	Depth to Water Below Land Surface (Meters)	Character of Water-Bearing Material	Remarks
37	4.80	3.30	Sand	Dug. Uncurbed. Good water
38	3.00	1.90		Dug. Uncurbed. Water slightly brackish
39	3.20	2.90		Dug. Uncurbed. Water slightly brackish
40	2.80	2.40		Dug. Uncurbed. Good water. In rainy seasons water level rises almost to surfa[ce]
41	10.60	Dry	Sand and gravel	Dug. Uncurbed. Water rises in well dur[ing] rainy season.
42	11.00	10.90	Sand with fine gravel	Dug. Uncurbed. Water temperature 28° C. Water level rises about 1.5 M. in the rainy season.
43	15.30	15.10	Gravel with sand	Dug. Uncurbed. Good water
44	17.40	17.30	Sand and gravel	" " " "
45	10.25	10.20	Gravel	" " " "
46	5.10	5.00	"	" " " "
47	7.25	7.20	"	" " " "
48	11.70	Dry	Limestone (?)	Dug. Uncurbed. Bottom of well appears to be in Eocene limestone.
49	7.60	7.50	Gravel	Dug. Uncurbed. Good water

TABLE I (Cont.)

Map No.	Depth (Meters)	Depth to Water Below Land Surface (Meters)	Character of Water-Bearing Material	Remarks
50	9.30	9.20	Sand	Dug. Uncurbed. Good water
51	17.70	17.60	Gravel with sand	" " " "
53	13.50	12.80	Coarse cobble gravel	" " " "
54	10.45	10.40	Sand and gravel	" " " "
55	0.40	0.30	Cobble gravel	Source Marchand. Flows in wet seas Natural well in dry season. In cha nel of Rivière La Quinte.
56	5.80	5.50	Sand with fine gravel	Dug. Uncurbed. Good water
57	5.00	4.40		Dug. Masonry curb. French colonia well. Water level rises about 1.8 in rainy season.
58	6.40	6.10	Sand with clay	Dug. Uncurbed. Good water.
59	9.50	9.40	Clayey sand with gravel	" " " "
60	6.10	6.00	Coarse cobble gravel with sand	Dug. Uncurbed. Good water. At Ferme Ecole de Dubedou. Water leve rises to within 2 M. of surface in rainy season.