Froide and the Grande Rivière de Léogane, particularly of their minimum flow, should be made over a number of years. River water undoubtedly would be much softer than the present spring supply and would deposit less scale in pipes. The Grande Rivière de Léogane should furnish water of as good or better quality than that of the Grande Rivière du Cul-de-Sac (p. 543), as most of its drainage basin is on basalt. Surface water would require sanitary purification either by filtration or chlorination. Filtration would be preferable and would have the advantage of removing some of the hardness.

Conclusions as to Port-au-Prince Supply.

Two courses are open for the improvement of the water supply of Port-au-Prince. One is to discard the present system and to substitute surface water from Rivière Froide or Grande Rivière de Léogane. Such a supply would have several advantages, chief among which are—(1) an abundant supply of water capable of expansion to meet the city's growing needs, such as providing for fire protection, sewerage, and irrigation of municipal parks; (2) softer water, which would deposit not nearly so much scale in pipes. Unfortunately, the cost of installation would be great and the city probably cannot afford it for a long time.

The other course, therefore, and the one that is much more likely to be followed, is to continue with the present system, improving it piecemeal as funds and other circumstances permit. Such new springs as can be appropriated should be added to the system and efforts to increase the flow of those now used should be made if they hold any promise of success. A spring-fed supply will always be subject to seasonal shortages. It should be remembered, however, that a shortage of water may be more apparent than real. If all leaks in the system were stopped, if waste were discouraged by metering the water to private consumers,[1] and if storage for the surplus night flow could be provided the city should have abundant water compared to what it has had. A spring-fed gravity system has certain advantages. The intake works are inexpensive and the conduits are easy to maintain. The present system also has the advantage of being already in operation. For these reasons it is likely to remain for some time.

CAP-HAÏTIEN.

Purpose of Investigation.

The water supply of Cap-Haïtien, like that of Port-au-Prince, is inadequate, especially in dry seasons. Late in February, 1921, several days were spent in a study of the geology in the vicinity of the city with reference to its water supply, and in April, 1921, a preliminary report was

[1] The initiation of some equitable plan for making the charges proportional to the quantity of water used is recommended in the Rapport de l'Ingénieur en Chef, 1920-1921, Port-au-Prince.

submitted to the Engineer in Chief setting forth possible ways in which the supply might be supplemented. The present report does not differ materially from the preliminary report. Some statements have been modified by late information and others have been altered to conform with the plan of the full report. In April, 1919, Conard[1] submitted to the Engineer in Chief a brief report on the water supply of Cap-Haïtien, from which some statements have been taken in regard to the distribution system and the quantity of water used.

Principal Features of Present Supply.

Cap-Haïtien stands on a very narrow alluvial plain that lies between the sea and a high, irregularly shaped mountain called the Morne du Cap. The public water supply is obtained from many small springs on the lower slopes of this mountain. The location of the springs, aqueducts, and reservoirs with reference to the city is shown in Figure 37. Almost all the springs now in use except Source Belair were developed carefully and utilized by the French colonists. The openings of the springs were cleaned out, generally to bedrock, and covered with massive housings of stone masonry. The water was conducted in large covered conduits to two masonry reservoirs that stand a considerable distance apart at the foot of the mountain west of the city. This part of the system is unchanged except for minor repairs. From the reservoirs water is distributed by a system of iron water mains installed in the later days of the Republic. A considerable number of private taps serve those who are well to do, but most of the patrons depend on public fountains.

The two reservoirs, known respectively as the Réservoir Justinien and the Réservoir Belair, are sunk flush with the surface of the ground and covered with masonry in six long parallel arches supported by columns. Their capacity as measured by the Hydraulic Service is a little more than 800,000 liters each.

The reservoirs are said to be capable of storing the full 24-hour flow of their respective feeders in normal times, but this statement appears to be a little dubious, for the flow of the springs supplying Justinien must be much greater, probably several times as large, as that of the springs supplying Belair. The statement would indicate a normal daily consumption of about 1,600,000 liters, which, for a population of 20,000, would be about 80 liters per capita a day, or only a little more than half the per capita consumption at Port-au-Prince, which is inadequately supplied. For other reasons the disparity is evidently not so great as the figures would indicate. The aqueduct and pipe lines at the cape appear to be in much better condition, so that the leakage is smaller than at Port-au-Prince, and the reservoirs aid greatly in conserving surplus water that

[1] Conard, R. A., Report from Dept. Eng. of North and Northwest to Engineer in Chief on Water Supply of Cap Haïtien, April 2, 1919. Manuscript on file in office of Engineer in Chief, Port-au-Prince.

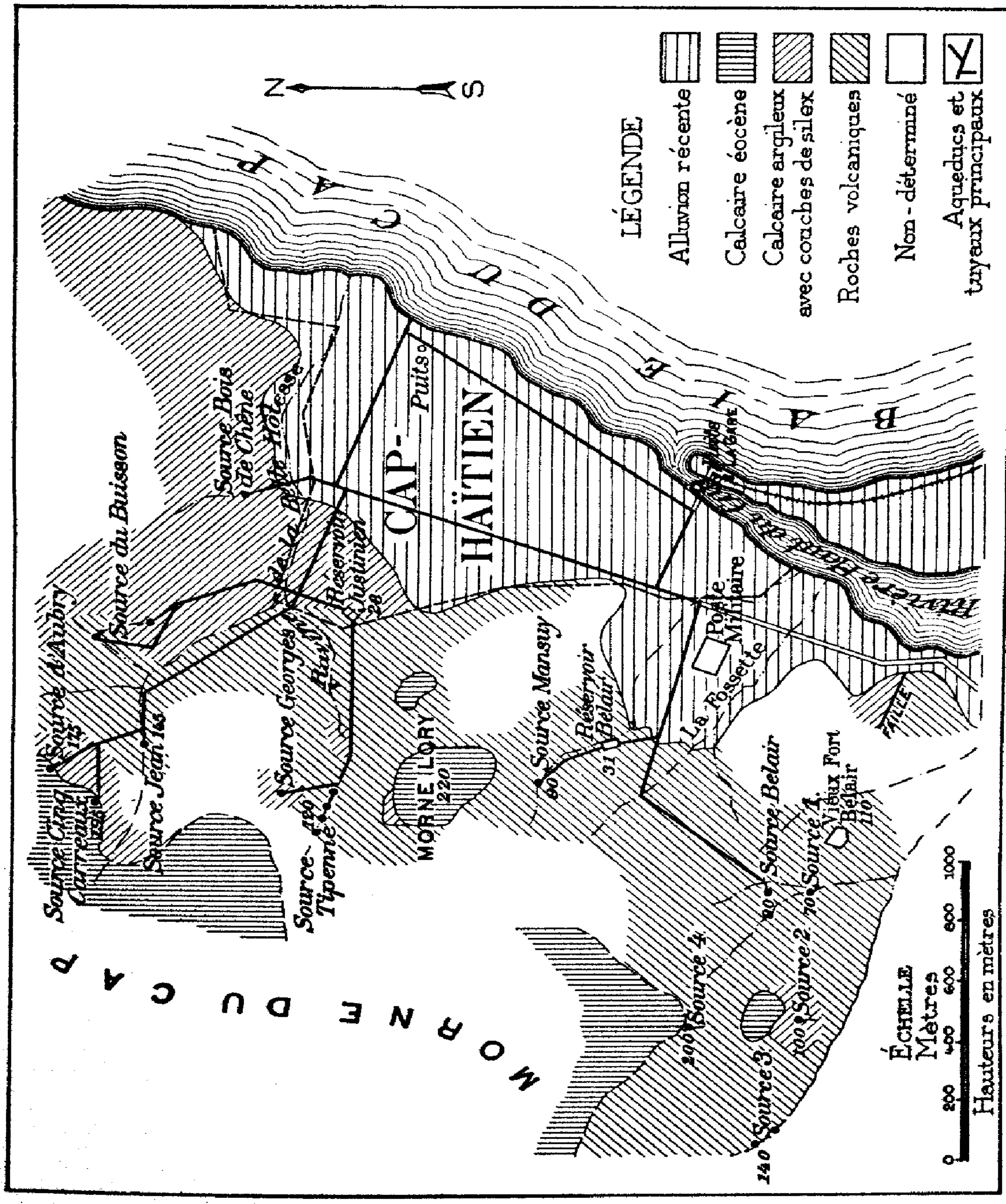

FIGURE 37.—Sketch map showing the water supply of Cap-Haïtien and its relation to the geology.

otherwise would be wasted. Besides, the practice of tapping off the water to private consumers at open manholes is probably not followed. The aqueducts are shorter so that maintenance is easier, and they are so large that there is no danger of their running full under pressure. Most of the iron mains are capable of bearing the pressure from the reservoirs, whose altitude above the town is not great.

The demands on the public supply are greatly lessened, moreover, by the use of shallow dug wells, on which nearly half the population depend. Conard[1] estimated there were 1,000 such wells in 1919. This fact is deplorable, for there are no sewers in the town and ordinary earth privies are used everywhere, so that the shallow water must be extremely unsanitary for drinking, for which it is undoubtedly used by many of the people.

The greatest defect in the water supply at Cap-Haïtien, as at Port-au-Prince, is the wide fluctuation in the flow of springs. Conard[2] estimated the minimum yield of the springs at less than 400,000 liters a day, or about one-fourth of the normal yield in wet seasons. In the winter of 1919-1920 many of the smaller springs were absolutely dry and the flow of the others was greatly diminished. To offset the deficiency a pump was placed in a shallow well near the water front in the heart of the city (Fig. 37), and for several months about 265,000 liters of water is said to have been thus pumped daily into the downtown mains.

The quality of Cap-Haïtien water is indicated by an analysis of a sample from the Réservoir Justinien, given on page 543. The water is comparatively low in total solids, of which calcium and magnesium bicarbonates, or common hardness, is the principal feature. It is chemically satisfactory, except that the minerals it contains tend to form incrustations in pipes or boiler tubes here, as at Port-au-Prince. (For a discussion of possible treatment for hardness see pp. 575-576.)

Geologic Features and their Relation to Water Supply.

ROCK FORMATIONS.

Groups distinguished.—For the purposes of this description four groups of rocks are distinguished in the vicinity of Cap-Haïtien, all of which are shown in Figure 37. The formations exposed in the Morne du Cap are volcanic rocks, probably of Cretaceous age; an impure clayey limestone that includes many beds of pure chert, also probably of Cretaceous age; and a pure white limestone, of upper Eocene age. In addition, Recent alluvium underlies the narrow plain on which the city stands and extends southward onto the North Plain, where it covers a large area (Pl. I).

Igneous rocks.—The igneous rocks may be divided into at least two series. One series consists of a dark basaltic rock, which is probably the oldest rock in the region. The other series comprises porphyritic rocks

[1] Idem.

[2] Idem.

of varying texture, which appear to be at least in part intrusive into the other volcanic rocks and into the impure Cretaceous limestone. In their bearing on water supply, however, they may be treated as a unit, and no attempt is made to distinguish them in Figure 37. Both rocks usually are brown or reddish on exposed surfaces. Unweathered specimens of the porphyry are dense and black except for clear crystals of quartz or light colored crystals of feldspar. Near the surface the igneous rocks have disintegrated, leaving a deep mantle of soil on the hillsides. Beneath this mantle they are jointed, so that they break out in irregular blocks. Volcanic rocks are widely exposed around the base of the Morne du Cap, west of Cap-Haïtien, beneath the younger limestones. The southern half of the quarry worked for road metal at the gateway south of the city is in igneous rock. Good exposures were seen also in the ravine below Sources Tipenne.

Impure limestone and chert probably of Cretaceous age.—The impure limestone, which is probably of Cretaceous age, overlies the igneous rocks in small patches west of the city and crops out extensively north of it at the base of the low spur of the Morne du Cap that is generally known as the Morne de la Vigie. It consists of beds of brown or yellowish impure clayey limestone, beds of black or bluish hard, splintery chert, and a few beds of dark sandstone and conglomerate containing fragments of igneous rock, probably the older volcanic rock. The cherty beds are the most distinctive feature of the formation. They are well exposed along the trail, on the beach north of Carenage, and on the hill just west of the Gendarmerie barracks. The beds of impure limestone are well exposed at Source Georges and near Sources Tipenne and Source Cinq Carreaux. Cherty beds are exposed also at the north end of the road-metal quarry south of the city near the city gate, where they are faulted into contact with porphyry. These rocks are minutely jointed and break up into very small angular blocks. On weathering they yield a rather clayey soil full of fragments of chert.

Upper Eocene limestone.—The upper Eocene limestone is a massive pure white limestone, gray and iron-stained on some weathered surfaces. It covers the higher part of the Morne du Cap and crops out in small patches on the lower slopes and foothills. The limestone is very soluble and loose blocks of it are honeycombed by pits due to solution. It contains underground caverns and solution channels which reduce it at places to a confused mass of huge, loose blocks. The upper Eocene limestone overlies the older, impure limestone and the volcanic rocks, and at the contact between them there is a basal conglomerate composed of pebbles of the older rocks. This conglomerate was seen around Source d'Aubry. Collections of fossil Foraminifera made at several places show that this limestone is of upper Eocene age.

Recent alluvium.—Most of the narrow plain on which Cap-Haïtien is built consists of Recent alluvium washed down from the adjacent mountains. It varies in texture from coarse gravel or boulders down to fine sand or sandy clay. Its maximum thickness along the water front is probably not more than 200 feet and may be even less. It is very thin or even absent on the western part of the plain, where the bedrock, consisting of impure limestone and chert, crops out. Such outcrops may be seen north and west of the Place d'Armes along the city streets and in the Ravine de la Belle Hôtesse.

This alluvial plain at Cap-Haïtien is a narrow projection of the large alluvial area of the North Plain (Pl. I), which in the region south and east of the Morne du Cap attains a width of 10 or 12 kilometers. The alluvium on the North Plain is finer textured than that in the city of Cap-Haïtien. Good brick clay is found at the Laroche brick factory, 2 or 3 kilometers south of the city. Probably the alluvium is thicker on the larger plain. Presumably all the alluvium rests upon bedrock like that which forms the Morne du Cap, probably chiefly igneous rock. Evidence of this fact is found in outcrops of igneous rock in low hills on the North Plain, such as Fort Vilton, Morne Beckly, and Morne Pelle.

CIRCULATION OF GROUND WATER.

Rain falling on the upper Eocene limestone sinks down quickly along open cavities and solution channels. At the base of this limestone its downward flow is checked and it moves laterally along the contact of the limestone with the underlying rock, which is less pervious. At some places it emerges along the contact as springs, such as Cinq Carreaux and d'Aubry. Where they are not too much weathered the impure limestone and the chert rock are rather pervious, containing fractures through which water sinks down to the underlying igneous rocks or at places near the shore to a water table controlled by sea level. The igneous rocks are the least pervious of all, but they absorb some water, though slowly, along cracks and joint planes. The residual soil and the weathered material above the igneous rocks absorb considerable water, which moves laterally along the surface of the unweathered rock beneath and issues as springs at places where outcrops of the bedrock or surface irregularities bring it to the surface. Source Belair and many smaller springs in the rock-floored parts of ravines originate in this way.

The alluvium under the city and in the North Plain doubtless contains a permanent body of ground water. Near the shore the water table stands approximately at sea level, but it rises gradually inland as the altitude increases. This water moves slowly seaward above the underlying bedrock.

NOTES ON PRESENT SOURCES OF SUPPLY.

The Réservoir Justinien is fed by springs, which rise in several ravines that converge in the northwest part of the city. The largest feeders are Sources Cinq Carreaux, d'Aubry, and Jean.

Source Cinq Carreaux is at the head of a steep ravine filled with great blocks of Eocene limestone, which rests upon the impure limestone and chert. The spring issues at the contact. It is protected by a massive masonry housing. Inside the spring house a trench floored with masonry extends across the ravine, and back of the trench is a stone wall. Behind the wall is an infiltration space filled with rubble, which probably rests on bedrock. Several openings in the stone wall admit water into the collecting trench. This is the typical French colonial method of developing springs and is very effective. Further excavation would not increase the flow of water, which at the time the spring was examined (Feb. 19, 1921) may have been 400 liters a minute. A few weeks before that time it was much less. This is the largest spring utilized in the water system.

Source d'Aubry is only a short distance from Cinq Carreaux, in a small ravine, where the geological conditions are almost the same. The spring emerges at the contact of upper Eocene limestone with the impure limestone and chert formation, and igneous rocks crop out near by. Water issues from a cavern, about 30 centimeters in diameter, in the limestone. The method of development is similar to that at Cinq Carreaux and can not be much improved. The flow of the spring was not more than about one-third that of Cinq Carreaux, and in dry weather it shrinks greatly.

Source Jean is in the bed of a deep ravine. A subsurface flow in gravel and alluvium appears to be brought to the surface by an outcrop of hard volcanic rock in the bed of the ravine. The bedrock surface appears to have been cleaned off carefully and the spring effectively utilized. The yield was perhaps one-third to one-half as great as that of Cinq Carreaux.

Sources Tipenne and Source Georges.—There are four springs, known as the Sources Tipenne, in the ravine back of the Réservoir Justinien and a fifth, called the Source Georges, in a tributary ravine. Each of these springs is at a place where a seepage of ground water in gravel of the ravine bed rises to the surface over ledges of bedrock. All have been developed by cleaning off the bedrock and digging a collecting trench across the ravine and placing behind it a masonry wall with a rubble fill at the rear. The springs are covered by heavy masonry housings and feed into a covered masonry aqueduct about a meter in height. Apparently all the available flow is obtained. The combined yield was not more than 100 or 200 liters a minute, and at times the springs are nearly dry.

Sources Du Buisson and nearby springs.—The name Du Buisson appears to apply to two springs north of the city. The largest is that in the ravine of the same name. It issues from soil and gravel that overlie volcanic rock. Some water appears to be lost by seepage here because the trenching is not deep enough, but the deepening of the excavation and the necessary lowering of the aqueduct would not be warranted, for the observed yield of the spring was only 40 or 50 liters a minute and the amount lost probably is even less.

The other spring consists merely of an excavation in soil on the hillside and yields little water, except in wet seasons. Several of the springs of this type are connected with the aqueduct, but they are not shown in Figure 37. They are practically nothing more than shallow wells or trenches in the smooth soil-covered hillside, and they were all dry when examined in February, 1921.

Source Bois de Chêne is a small spring, probably resembling Source du Buisson. It was not examined.

Source Belair is the principal feeder for the Belair reservoir. It is at the foot of a steep and slightly concave slope between two ravines in an area of volcanic rocks. The bedrock is covered by a deep mass of soil and talus, and the water appears to come from slow seepage in this rubble over the less pervious surface of the unweathered rock below. The spring has been developed by cutting away the hillside and digging a trench about 2 meters deep and 30 meters long parallel to the face of the hill. The trench walls are supported by masonry, and water passes through the wall on the lower side into a covered springhouse and is carried by iron pipe, 10 inches in diameter, to the reservoir. As the trench does not extend down to solid bedrock considerable water is no doubt lost by seepage, which might be saved by deepening the trench to solid rock. This would necessitate lowering the intake. If the depth to rock should be too great to permit convenient lowering of the conduit the water level might be raised to the intake by building a concrete retaining wall on the bedrock along the front of the trench with wings extending up the side of the hill at either end, if necessary. As the Belair spring is the principal feeder for the Belair reservoir and the main dependence of a considerable part of the town, this improvement probably would be justified.

Source Mansuy consists of a seep rising over igneous bedrock in a steep-sided ravine. When examined in February, 1921, it was virtually dry. There seems to be no chance to increase its yield.

Additional springs available.—The French colonists seem not to have overlooked any available springs on the slopes of the Morne du Cap that are adjacent to the city. The surface features and the geology do not suggest any localities favorable for the easy development of an additional supply of water that would flow to the city by gravity. There are, however, a few springs west of Belair in an adjacent drainage basin that could be connected to the Belair pipe line. The names of these springs were not obtained, and they are indicated by numbers on Figure 37. All these springs except No. 3 may be reached by a trail leading nearly westward from a locality between Fort Belair and Belair spring.

Spring No. 1 is on a rolling soil-covered slope a little more than 100 meters south of Belair spring. It was yielding probably 100 liters a minute when examined, not including the flow of two small seeps a little higher up the slope. Perhaps a little more could be obtained by trenching. Unfortunately, this spring lies about 10 or 15 meters lower than the divide south of Belair spring and could not be connected to the Belair pipe line. It might be carried in a separate pipe line around to the south of the hill on which the old fort stands, but it is doubtful whether the quantity of water obtainable would warrant the expense.

Spring No. 2, the name of which was reported to be Limbère, is about 500 meters west of Source Belair and, according to the aneroid barometer, at least 10 meters higher. If this altitude is correct, the spring could be connected to the Belair pipe line, but a careful survey would be necessary to confirm the altitude. The spring issues on a steep hillside from a small body of upper Eocene limestone that appears to overlie some of the impure limestone and chert. The observed flow was probably from 40 to 80 liters a minute and might be increased a little by opening up the outlet.

Spring No. 3 is really a series of springs or seeps in the bed of a deep ravine, which give rise to a small brook that flows for a considerable distance through the principal valley south of Source Belair. The most favorable locality for its utilization is near the head of seepage a little above the crossing of a prominent trail that leads westward up this valley, where the altitude is about 140 meters above sea level. The water should be developed by putting down a water-tight dam across the ravine to bedrock, which crops out at many places. It would probably be advisable also to put in a fill of loose stones above the dam to the head of seepage. The yield of the spring would probably be from 100 to 200 liters a minute.

Spring No. 4 is on the slope directly above Spring No. 2, about 100 meters higher. The spring issues from a deep soil fill on a flat bench, but the water probably comes originally from the contact of upper Eocene limestone and volcanic rock in the ravine above only a few meters distant. A survey by the Hydraulic Service is said to have shown that it would require 800 meters of pipe line to connect this spring directly with Belair. This measurement appears to be considerably greater than the direct distance between the springs, but the difference may be due to difficulties in the terrane. The better plan, if springs 2 and 3 were being developed, would be to run a pipe line directly down the hill to No. 2. The yield obtainable probably would be 100 liters a minute or more. In developing this spring the soil should be deeply trenched, to bedrock if possible.

Well Water.

WELLS IN THE CITY.

The well that served as a source of an emergency supply in 1921 is in the heart of the city, near the water front. (See Fig. 27.) It formerly supplied water for a soap factory, which has been abandoned. It appears to have been made by driving a 4-inch pipe down into the alluvial sand and gravel and washing out or boring out the dirt inside. It is 5 meters deep and the water in it stood about 1.4 meters below the surface of the ground, which is here only about 1.5 meters above sea level. About 263,000 liters of water daily, measured in a large steel tank, is said to have been pumped from this well for 3 or 4 months by a small steam pump. The drawdown was considerable, and the pumping is said to have caused a nearby dug well to go completely dry. No saltiness from the sea was noted, however, although the well is only about 45 meters from the shore. Sanitary examination is said to have shown the presence of colon bacilli in this water, and its use is dangerous in view of the very unsanitary condition of the ground in the city.

Wells designed to supplement the present supply of water should be dug or drilled as near the city as possible, to avoid the expense of pumping a long distance. Geologically the most favorable location would be on the alluvial plain near the heart of the city, for most of the ground water from the mountains passes under this plain on its way seaward. Wells anywhere in the thickly inhabited area are out of the question, however, for the water would be too much contaminated. A great deal of sewage and fecal matter is thrown on the ground all over the city and even beyond its limits, and in addition many earthen privies are in use. There is no impervious cover to prevent filtration downward, and percolating water undoubtedly carries polluting material into the ground water beneath the city. Even deep wells carefully cased probably would yield contaminated water if they were pumped heavily.

Two localities for wells near the city might be considered. One is along the valley of the Ravine de la Belle Hôtesse, in the northern part of the city. To avoid pollution, wells would have to be placed almost on the mountain sides. There is one fairly clean spot north of the ravine between the Civil Prison and the Gendarmerie barracks below the Source Bois de Chêne. This spot is far to one side of the valley and is not favorably situated to yield a large volume of water. Any well in this area will strike bedrock (impure limestone and chert) within a few meters of the surface, and probably would have to be drilled. The individual yield of drilled wells is not likely to be very large and will decrease rather than increase with increase in depth beyond 100 or 200 meters, because the water-bearing fractures become smaller with increase of depth. Wells in this locality would therefore have the several disadvantages of hard rock drilling, deep well pumping, inadequate supply, and possibly also unsanitary water.

The other possible location is in the small alluvial valley southwest of the city, in the locality generally known as La Fossette, near the military encampment. In the vicinity of the military encampment and to the west the ground is fairly clean, although the city, immediately to the east, is not. There is a considerable alluvial fill here. The depth to the permanent water level probably is not more than 8 to 15 meters. It is said that water was found at a depth of 5 meters in the northeast corner of the military encampment. Wells sunk into the alluvium probably would yield more water than deep wells drawing from the underlying bedrock. They probably would not need to be more than 30 meters deep, at least no deeper than the bedrock. Two or three wells about 6 inches in diameter, spaced at intervals of 20 to 40 meters and placed anywhere in or near the southern border of the military encampment, should be sufficient. The water could be pumped readily into Belair reservoir. The drainage basin tributary to the valley is very small and probably would not yield enough water to constitute more than an adjunct to the present supply. As such it is worthy of consideration if no other improvements are attempted.

POSSIBLE YIELD OF WELLS NEAR THE CITY.

Rough measurements on three different maps, none of which are very accurate, indicate that the area drained by the several ravines crossing the little alluvial plain of Cap-Haïtien is about 5 square kilometers. About half of this area lies above and tributary to the springs that now supply the city.

The mean annual rainfall at Cap-Haïtien for 12 years has been about 1,584 millimeters (see p. 50). On the areas of upper Eocene limestone a large quantity of water is absorbed in caverns in the rocks, but the limestone areas are very small, constituting only the higher summits and a few outlying patches. The other rock formations are less porous, and the clayey soils by which they generally are covered favor a greater run-off, perhaps as much as 50 per cent. Everywhere considerable water is lost by evaporation or dissipated by plant growth.

The proportion of the rainfall that becomes ground water therefore probably does not exceed one-fourth to one-half. Not nearly all of this could be obtained, even by an elaborate system of wells. Possibly as much as one-fifth of the total rainfall might be developed effectively. This would be 317 millimeters per annum. Allowing the full area of 5 square kilometers it would amount to 1,585,000 cubic meters of water, or a supply of 4,340,000 liters daily. This includes polluted water from the surface of the city. The small valley at La Fossette has a drainage area of not much more than one square kilometer and, according to the above calculations, might yield about 900,000 liters daily.

The present yield of the springs must be deducted from any estimate of the quantity of water available for wells, for it represents developed ground water. The total flow appropriated probably averages about 1,200,000 liters daily. Only a small fraction of this amount is to be deducted from the estimate of water available in La Fossette.

WELLS ON THE NORTH PLAIN.

An unlimited supply of well water could be obtained on the North Plain at a distance of 4 or 5 kilometers from the city. This region receives the drainage from a large area of mountain and plain to the south and there is undoubtedly a great body of fresh ground water beneath it. Flowing water under very low pressure might perhaps be obtained (see pp. 538-539), but the flows are not likely to be large and pumping would certainly be necessary to bring the water to the city.

That part of the North Plain nearest the city is not a suitable place for wells because, with the exception of a narrow sand bar between the river and the sea, it is a salt marsh and is flooded at high tide. Deep wells for a large pumping plant would have to be drilled south of the marshes, at a safe distance from salt water. Any place 100 or 200 meters from the salt marshes would be satisfactory, for the salt water covers this area only a part of the time and the quantity of fresh ground water seeping seaward is great enough to prevent an ingress of salt water unless the wells were pumped very rapidly, much more rapidly than will ever be necessary to supply abundant water for Cap-Haïtien. Probably the best location for wells is south of the salt marshes and east of Rivière Haut du Cap. If it is highly undesirable to cross the river, however, a fairly good location could be found farther west, between the road and the river, in the vicinity of the Laroche estate. Unfortunately, both of these locations are 3 or 4 kilometers from the city gate, but they appear to be the best available.

It should be easy to drill wells on the plain, for the alluvium is soft. The maximum depth to which it would be necessary to drill is probably 150 meters, and bedrock may be reached at less depth. To obtain large yields the wells should be at least 6 inches in diameter, and the casings should be perforated at all good water-bearing horizons. Yields from 500 to 2,000 liters a minute might reasonably be expected, according to the pumping equipment and the amount of drawdown. It is possible that one large well with a deep-well pump would supply all the water needed, but there might be danger, with the great drawdown that would result, of drawing in salt water from the neighboring marshes. It would be better to have a number of wells spaced several meters apart and pumped from a single suction main. At present, probably one or two such wells would furnish all the water needed to supplement the flow of the springs in periods of deficiency. Such a plant could be expanded indefinitely and could even be made the sole source of supply.

Well water from the North Plain should be satisfactory; at least it is not polluted. The plain is thinly settled, especially in the locality suggested for the pumping station, and there are in the alluvium beds sufficiently impervious to prevent any local pollution from extending to the deeper beds.

The only known well that may show the possible value of deep wells on the plain is at the railroad station at Cap-Haïtien (Fig. 37). This well is on the narrow bar that separates the tidal river mouth from the sea, and is at an altitude of less than a meter above sea level. It is only about

60 meters from the bay and 5 meters from the river. The well is 3 inches in diameter and 26 meters deep. It was made by driving a pipe into the ground with a drop-hammer and removing the dirt inside later. According to Mr. Holland, who made the well in 1911, water was struck at 10 meters and rose to the surface. For a time the well flowed slightly. The material penetrated was loam, sand, and gravel, successively. This well is the sole supply of the railroad station. Its water is satisfactorily used in locomotive boilers. It is pumped at a maximum rate of about 10,000 liters in 12 hours and the average daily consumption is about 40,000 liters.

An analysis of this water is given on page 544 and is illustrated graphically in Figure 32 (p. 548). The total solids are rather high, and the large proportion of alkali chloride as well as the preponderance of magnesium over calcium strongly suggests that it is contaminated by sea water, which is not surprising. Evidently the water contains also a large quantity of sodium carbonate, which must have resulted from the interaction of seawater with bicarbonate-bearing ground water. Water from places farther inland would contain less total solids and a good deal more calcium bicarbonate, but should be good for a city supply. The record of this well is encouraging in that it indicates the presence of a large supply of ground water with a little artesian head in the area around the mouth of Rivière Haut du Cap. A large pumping plant at this locality is out of the question, because the water obtained would certainly become badly contaminated by sea water.

Surface Water.

No surface water with gravity head can be obtained nearer to Cap-Haïtien than the mountains south of the North Plain. Conard[1] recommended bringing water from the headwaters of Rivière Haut du Cap, 21 kilometers south of the city. The water probably would require filtration for sanitary purification. It would constitute an ideal supply, but the installation would be very expensive. A pumping plant would be preferable as a measure of temporary relief, but surface water is worthy of careful consideration for a future enlarged supply.

Conclusions as to Cap-Haïtien Supply.

As indicated above, there are four possible ways in which the water supply of Cap-Haïtien can be improved:

First, certain springs could be added to the present supply, and the flow of Belair might be increased a little, thus adding to the present supply by 20 to 25 per cent. This would not remedy the principal defect of the system, however, which is the great seasonal variation in flow. Nevertheless it is a desirable improvement if nothing better can be attempted, for spring water under gravity head is always cheap water.

[1] Op. cit.

Second, the spring flow could be assisted in periods of deficiency by a small pumping plant near the city, preferably one near La Fossette, which is also desirable if nothing else can be done, and could easily be installed to augment the supply obtained from springs.

Third, a large pumping plant in the North Plain could be made to supplement the spring flow or to replace it entirely. The water would probably be of excellent quality, and the only reason for hesitating to adopt this plan is the expense of installation and maintenance.

Fourth, a surface water supply could be brought from some river, probably the Haut du Cap, in the mountains south of the North Plain. This also is an excellent plan, the chief objection being the expense of installation.

Whatever plan may be adopted, it will be desirable to use all or at least some of the springs to supply the higher outlying parts of the city.

NOTES ON WATER SUPPLY OF SOME OTHER TOWNS AND VILLAGES.

Port-de-Paix.—All the drinking water used in Port-de-Paix is carried on burros from Les Trois Rivières, which is at a considerable distance from the city. Some water of poor quality, used for certain domestic purposes, is obtained from shallow wells in the alluvium that underlies the city. In the hills south of Port-de-Paix there is an old colonial reservoir in which water from small mountain streams was impounded and thence led to the city in a masonry conduit. The Gendarmerie post uses a small reservoir located south of the Champs de Mars to store water from a small stream. It is brought to the barracks in an old colonial conduit, but because of pollution is not used for drinking.

The possibility of utilizing any part of the old colonial gravity system was not investigated. It is not likely that valuable artesian flows can be obtained near the city, and the best source for a city supply would probably be Les Trois Rivières. The water would require purification.

Môle St.-Nicolas.—Most of the water used for domestic supply at Môle St.-Nicolas is carried on burros from Rivière du Môle, which disappears in stream gravels about 3 kilometers from the sea south of the town. Frequently the water is collected carelessly at the lowest point of flow, where it is badly polluted by the washing of clothes and by refuse. Water from shallow wells in the small alluvial plain at the city is used to some extent, but it is said to be often brackish, and it is doubtless unsanitary. The town should have an aqueduct to bring water from the locality called La Gorge, on Rivière du Môle. Purification would be desirable, but even without it the water would be greatly preferable to that now in use.

Baie de Henne.—The only water available for domestic use at Baie de Henne comes from a brackish spring that issues from the limestone sea cliff at the southeastern edge of the village. The cliff consists of Qua-