hold the hand in either spring indefinitely without discomfort. There are no bathing facilities except a sort of earthen-walled and rock-floored basin that has been scooped out at the lower spring. A quaggy area of mud below the other spring is a favorite place for mud baths. The taste of the water is not unpleasant.

Aside from other considerations the temperature of this water is not high enough to necessitate the assumption that it is either of magmatic origin or that it has been heated by buried intrusives. All its heat might easily result from circulation along deep fractures, joints, or fault zones. The analysis shows, however, that the water is decidedly different from that of the other warm springs and in fact from that of all the other waters of the Republic for which analyses are available.

Analysis of water from the Sources Chaudes de Dame-Marie or de Jérémie.

[Parts per million. C. S. Howard, analyst.]

Total dissolved solids	515
Silica (SiO_2)	68
Iron (Fe)	.07
Calcium (Ca)	26
Magnesium (Mg)	1.4
Sodium and potassium (Na+K)	135
Carbonate radicle (CO_3)	.0
Bicarbonate radicle (HCO_3)	93
Sulphate radicle (SO_4)	117
Chloride radicle (Cl)	121
Nitrate radicle (NO_3)	.42
Date of collection	Nov. 16, 1920

This analysis is represented graphically in Figure 32, page 548. In view of its probable circulation at considerable depth the water is not highly mineralized. The alkali sulphate and chloride are relatively very high, particularly the sulphate. Calcium and magnesium bicarbonates are very low compared to those found in the normal waters of the Republic. Silica is unusually high. The last two features might be interpreted as favoring a magmatic origin for the water. The differences between this water and other mineral waters of the Republic may arise chiefly from its circulation entirely through volcanic rocks, but the occurrence of many warm springs in this area, which is an area of volcanic rocks, might strongly suggest that this water is of magmatic origin.

PUBLIC WATER SUPPLIES.

PORT-AU-PRINCE.

Purpose of Investigation.

The water supply of Port-au-Prince has been for many years unsatisfactory and inadequate for the needs of its growing population. Owing to long-continued dry weather the shortage of water in 1919 and 1920 was distressing. The writer therefore spent about two weeks in October, 1920, in a study of the geology of the vicinity of Port-au-Prince with special reference to its bearing on the present and possible future sources of water supply. The results of this study were submitted to the Engineer in Chief in the same month in the form of a preliminary report. The substance of this preliminary report is given here, with such modifications as have been suggested by later developments and with the omission of certain material that is given elsewhere in this report.

Sources and Distributing System.

The water for Port-au-Prince is conveyed to it from springs in the foothills of Morne Hôpital, south of the city. The location of these and other springs and their relation to the principal geologic features are shown in Figure 36.

The springs used are Plaisance and Cerisier, Turgeau, Le Clerc, Chaudeau, and Diquini. Sources Chaudeau and Diquini have been added to the supply in recent years, Diquini having been connected only in 1921. The others were appropriated by the colonists soon after Port-au-Prince was established and have served continuously since.

In utilizing a spring an excavation has been made at its visible outlet to remove all soil and loose material so far as possible and a masonry housing has been placed over the excavation. Open stone aqueducts were used by the colonists to carry the water to the city, but these aqueducts have probably all been replaced or repaired, and the newer lines to Chaudeau and Le Clerc are constructed in great part of large cast iron pipe. All the masonry conduits now in use are covered, although holes have been broken in the covers at many places and some of them are poorly repaired. None of the aqueducts is strong enough or tight enough to carry water under pressure, and large manholes (regords) are therefore introduced in the line at intervals of about 100 or 200 meters. The manhole is a large square chamber about 2 meters deep with an iron cover. It receives water from the section above and discharges it by overflow into the section below, thereby dissipating any pressure accumulated in the closed aqueduct above. As a matter of fact, however, the aqueducts seldom run full except at points where inverted siphons are used to carry the water across deep ravines.

In the higher, more fashionable residence sections of the city the water is distributed through private pipe lines of very small diameter, which are tapped into the manholes. Ten or twenty such lines may be inserted in one manhole and some of them are as much as a hundred meters long. The pressure depends of course upon the height of the manhole above the consumer's tap.

In the downtown business section the water is distributed through cast iron mains of different sizes, most of them 4 to 6 inches in diameter.

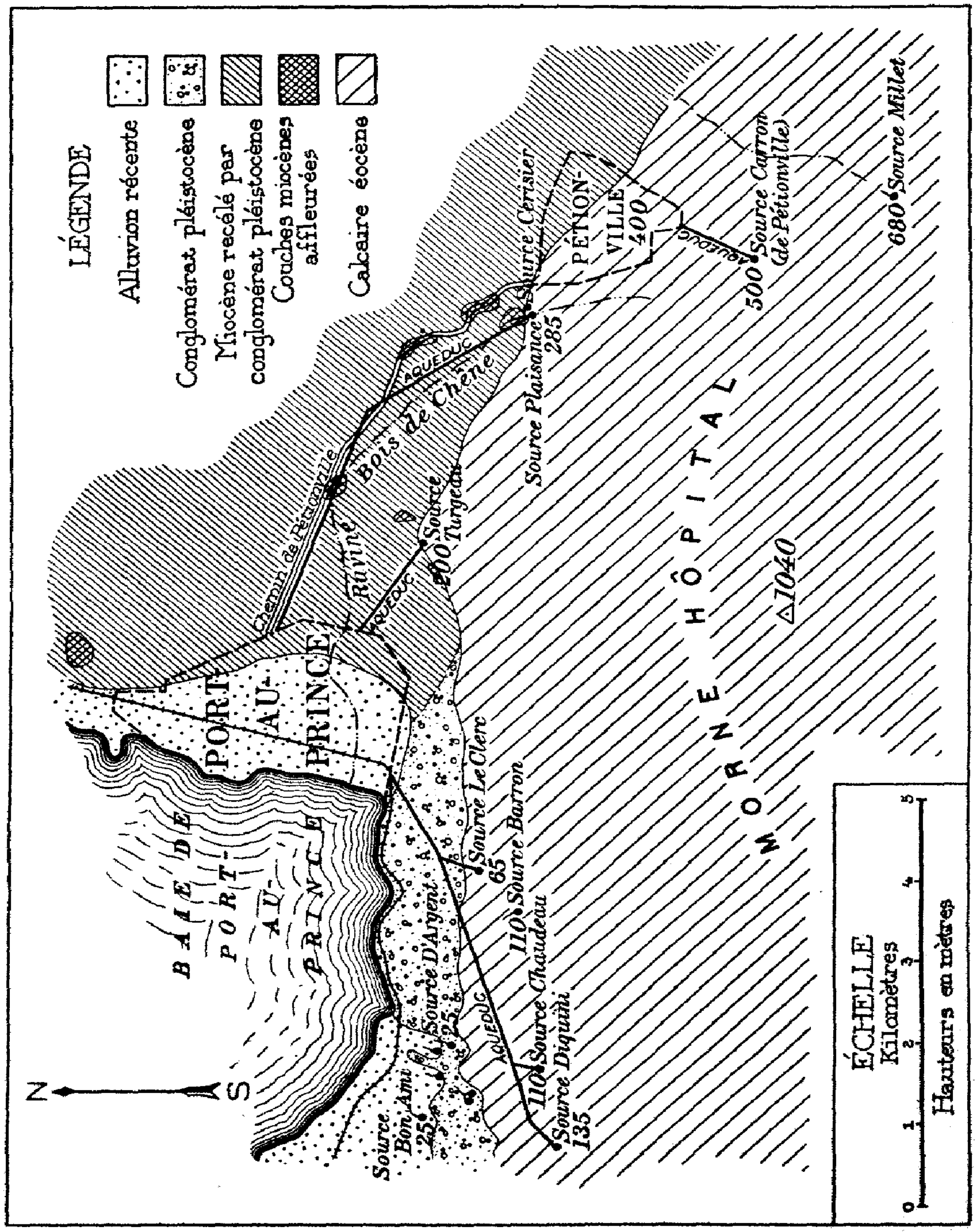

FIGURE 36.—Sketch map showing the water supply of Port-au-Prince and its relation to the geology.

These mains, like the aqueducts, are in poor repair and are unable to bear much pressure, so that no attempt is made to keep the system tightly closed. Most of the people obtain water from public fountains, some of which run continuously if there is any water in the pipes, and excess water is allowed to waste.

Calcareous deposits in the water mains are a source of much annoyance and expense. The small private pipe lines become stopped up in a few years, and even many of the large city mains have been almost entirely closed by such deposits.

The water service is not metered in any part of the city. Owing to the defects in the water supply, fire protection in the city is very inadequate. There is no sewer system whatever.

Although the present water supply system is very imperfect and inadequate, owing to its inherent and inherited defects, the present Hydraulic Service is doing much to improve it with the scant facilities and funds available.

Yield of Springs.

No accurate data are available to show the quantity of water yielded by the springs that supply Port-au-Prince. Two estimates, based apparently on single measurements, are as follows:

Yield of springs supplying Port-au-Prince.

Source.	Liters per second.	
Plaisance and Cerisier	[a]30	[b]66
Turgeau	[a]17	[b]37
Le Clerc	[a]25	[b]25
Chaudeau	[a]30	[b]44
Diquini	[c]80	[c]80
Total	182	252

[a] From report of Thomas Price, engineer, to M. John Laroche, Secy. d'État, Dept. des Travaux Publics, July 29, 1914.
[b] From Report of R. A. Conard, civil engineer, U. S. N., to Engineer in Chief, May 6, 1918.
[c] Oral communication by Lieutenant Diehl, Dept. des Travaux Publics, 1920.

If the springs supply an average of 200 liters a second the daily total is from 17 to 20 million liters. For an estimated population of 125,000 this is about 150 liters per capita a day, a very fair quantity compared to many large cities in all countries except the United States, where the average is considerably higher. A great deal of the water is practically wasted through leaky pipes, running fountains, careless use by patrons favorably situated at high altitudes, and especially because there is no storage space to conserve the surplus night flow.

Another serious fault is that the flow of the springs fluctuates greatly from season to season as all the springs depend on rainfall for their maintenance. The actual amount of such seasonal fluctuations is not certainly known, but it can be judged from the records at Source Despuzeaux (p. 517), which indicate that the maximum flow is nearly three times as great as the minimum. A series of dry years, such as is not uncommon, causes great water shortage. This defect is unfortunately inherent in nearly any spring-fed system in regions where the rainfall is unevenly distributed, and its consequences are aggravated by habits of wastefulness acquired during times of super-abundance of water, which persist during periods of shortage.

Geologic Features and Their Relation to Water-Supply.

As there was no suitable base map and as little time was available it was impossible to map the geology near Port-au-Prince in detail. Most of the work had to be done on foot, for the country is very rugged and most of the uncultivated mountain slopes are covered with thick brush. There are four distinct series of sedimentary rocks in the region. Their general distribution is shown in Figure 36. The Miocene beds are probably exposed at many more localities than are shown on the map.

Limestone of late Eocene age (see p. 130) forms the mass of Morne Hôpital and is the oldest rock in the region. It is hard and white. Some parts of it are massive; other parts distinctly show bedding planes. It is strongly folded, so that the beds dip steeply, generally northward, on the north side of Morne Hôpital. Some faults are known and joints are very common. Many of the joints and bedding planes have been enlarged by solution and form channels for the circulation of ground water. The presence of sink holes on the broader part of the crest of Morne Hôpital indicates that solution has been very active and has formed large underground cavities. Because of its porosity the limestone absorbs water freely and most of the drainage is subterranean, surface streams flowing only during heavy rains. The water absorbed by this limestone gives rise to all the springs near Port-au-Prince. The other rocks are important chiefly for their influence in determining the location of springs, most of which are in ravines among the foothills at the base of Morne Hôpital.

In the rolling hills east of Port-au-Prince outcrops of soft Miocene beds (see pp. 219-221) are found in road cuts and along ravines. These beds underlie this region continuously but are concealed at most places by younger rocks. The Miocene series here comprise beds of coarse conglomerate, silty sandstone, limestone, and clayey marl. These beds, like the beds of Eocene limestone, are sharply folded, the axes of the folds trending east-west or northwest-southeast. The beds of marl and silty sandstone are relatively impervious, especially the marl. Consequently, where the Miocene beds abut against the base of Morne Hôpital they form a barrier or dam to the ground water that is stored in the upper Eocene limestone and that is seeking an outlet at the base of the mountains. Sources

Plaisance, Cerisier, and Turgeau are apparently due to the escape of water that overflows this impervious barrier.

South and west of Port-au-Prince, at the base of Morne Hôpital, there is a belt of foothills of gentler slope than the main mountain mass. These foothills are composed of roughly stratified beds of coarse conglomerate consisting chiefly of limestone pebbles, and are probably of Pleistocene age. East of Port-au-Prince this conglomerate still covers the foothills but is nearly everywhere underlain by Miocene beds, although at some places it extends above them on the mountain side. The conglomerate is not folded, but it is considerably dissected. It is a porous rock and probably here and there absorbs a good deal of water from the upper Eocene limestone.

In the lower part of Port-au-Prince and at other places near the shore there is a belt of Recent alluvium, consisting of horizontal beds of gravel, sand, and clay. These sediments are not consolidated and are but little dissected. They underlie the narrow coastal plains. The alluvium is less pervious than the Pleistocene conglomerate, and ground water seeping seaward into the conglomerate at some places is forced to rise above the contact of the alluvium in springs, as in the group of springs including Source Bon Ami and Source d'Argent.

Some springs, like Le Clerc, Chaudeau, and Diquini, do not appear to be related to geologic contacts but occur at places where deep ravines in the foothills tap underground streams in the upper Eocene limestone.

Notes on Individual Springs.

Source Diquini issues in a deep, narrow ravine in upper Eocene limestone at a locality where the gradient increases rapidly upstream. Water originally rose through a few meters of alluvium in the bed of the ravine. This alluvium has been cleared away to solid rock, from which the water appears to come, and a concrete housing several meters long and wide has been constructed over the outlet. The spring appears to be effectively utilized.

Source Chaudeau, like Diquini, is in a deep ravine and probably issues from solution channels in the upper Eocene limestone, which crops out on both sides of the ravine. One small isolated vent west of the main source issues from bedding planes of the limestone. Most of the water, however, is contained in alluvial gravels, a few meters in depth, in the bed of the ravine. In developing the spring a concrete floor was laid over all this gravel bed for about 100 meters. This floor was intended to protect the water from pollution by floods or by careless local use. The water is collected in a deep pit that penetrates the gravels at the lower end of this concrete cover. The pit is covered by a concrete housing. The flow is probably developed about as advantageously as possible, unless perhaps the pit fails to reach bedrock and some water is lost by seepage. A little water could be appropriated from the small outlet at the side, but it would not increase the yield a great deal.

Source Barron was not visited. The Hydraulic Service is said to have considered connecting it with Source Le Clerc, but decided that its small yield would not justify the expense.

Source Le Clerc is at the head of an especially narrow and steep-sided ravine. Limestone is exposed in a small bluff high above the spring, but the bottom and sides of the ravine are deeply covered by alluvial or residual soil, from which the water seeps out. The spring has been developed by a shallow excavation in this alluvium and has the usual concrete housing. Considerable water may be lost at this spring by seepage through the alluvium, and a good increase in flow probably could be obtained by sinking the excavation deeper, to bedrock if possible. This work however, would necessitate either lowering the aqueduct or building a water-tight subsurface dam, set on bedrock across the ravine.

Source Turgeau is in a remarkable natural amphitheater, about 100 meters in diameter, walled on three sides by steep slopes of upper Eocene limestone. On the other side it opens into a shallow ravine. The spring appears to be on the contact betwen the limestone and the Miocene beds, but the Miocene beds are obscured by a thin cover of Pleistocene conglomerate. Outcrops of Miocene rock are found both east and west of the springs. The water probably comes through solution channels in the limestone and rises over the dam formed by impervious Miocene beds. The outlet is obscured by soil and débris, however, and the water seeps out over a large area in the bottom of the basin-like depression. The spring has been developed by digging a series of ramifying trenches, 1 or 2 meters deep, in the soil. Water rises with some force in these trenches and collects to form a large stream. As the water appears to rise under some pressure through the confining soil the writer suggested that a larger and freer flow might be obtained by sinking some wells to considerable depth, to bedrock if possible, in the area where the trenches were constructed. This was tried but was found to be very difficult because of the water itself and because of the large boulders encountered. A substitute plan was then tried. It consisted of digging a long trench across the ravine below the springs, and placing a subsurface dam there to impound any seepage that might have escaped through the conglomerate and soil. The results of this experiment are not yet known.

Source Plaisance is in the bed of the Ravine Bois de Chêne, which is dry except during or immediately after rains. It is a considerable distance from the mountain front, although outcrops of upper Eocene limestone were seen not far away in the bed of the ravine. The water, however, appears to be mainly seepage water in alluvial gravels or in Pleistocene conglomerate in the stream bed. This seepage water is forced to rise to the surface by a dam of impervious Miocene beds that crop out in the ravine. At a point just below the spring these beds strike N. 75° W. and dip 43° SW. They form a very effectual barrier to underground seepage. The excavation made in utilizing Source Plaisance is very shallow and extends only partly across the ravine bed. It would be better if it could be made a little deeper and wider, but the natural dam appears to force all the water to the surface and probably none is lost except the small quantity that is visible for some distance below the spring and that is left for the use of people who live nearby.

Source Cerisier is in a tributary ravine only a short distance from Source Plaisance and owes its origin to the same geologic feature. Its flow, however, is very small, and it becomes virtually dry in the dry season. There is little hope of developing more water from it.

Source Carron supplies the town of Pétionville. No especial attention was paid to it. At the point where it is utilized it consists of underflow in an enormous boulder fill in the bed of a ravine. The width of the boulder fill is 50 meters or more, and its depth is probably 10 or 15 meters. The boulders at the surface are from 15 centimeters to half a meter in diameter. The spring has been utilized by digging a deep pit in the boulder fill and housing it with concrete.

Source Millet, which appears to have other names, is a large spring 2 or 3 kilometers south of Pétionville, in the second large ravine east of that town. It is the largest unappropriated source of water available to supplement the Port-au-Prince supply. The spring is very near the trail to Furcy, which traverses the ridge just west of it. It is used only to a small extent by inhabitants near by.

The spring is in a large bouldery stream channel much like that described at Source Carron. Most of the water is contained in the boulder filling; only small flows—a few liters a minute—break out here and there at the surface at places where the boulders have been scooped out either naturally during floods or intentionally by people seeking water. The water is held up near the surface by beds of dense upper Eocene limestone, which are tilted vertically across the ravine. The most favorable place to develop the water is near the present area of largest flow, where the ravine is reasonably narrow and has walls of solid rock. If possible, all the loose material should be excavated in order to collect all the flow in the lowest part of the bedrock floor beneath the boulders. It is not easy to estimate the quantity of water available, but apparently there is a large flow beneath the surface. It would be difficult to construct an aqueduct, especially for the first kilometer, where the ravine is bouldery and steep-sided. The altitude of the spring, however, would permit diversion of the water into the Plaisance-Cerisier aqueduct at any desired locality.

Source Bon Ami, Source d'Argent, and near-by springs.—There is a group of small springs near Bizoton, the best known of which are Sources Bon Ami and d'Argent. They are at the rear of the narrow alluvial plain and are apparently supplied by ground water in the Pleistocene conglomerate, which is forced to rise over the impervious alluvium to reach the sea. They are at altitudes probably between 25 and 40 meters above sea level, and their water could not be carried by gravity to any but the lower parts of Port-au-Prince. They might perhaps be used to good advantage in this way, for the water from all could be brought together easily and the terrane is favorable for the construction of a conduit. A large part of the water, however, is now used in irrigating land near the springs.

Other springs.—The inhabitants of the region know all the large springs but persons unacquainted with the country have difficulty in discovering some of them. Some small springs were doubtless not found by the writer, but probably none that are conveniently situated.

Well Water.

Because of the high cost of machinery and fuel it is not considered feasible to pump water for Port-au-Prince from wells, but flowing artesian water, if obtainable at altitudes that would permit its distribution by gravity, would be advantageous. There are few wells in the region and none of any considerable depth, so that any opinions as to the occurrence of ground water must be based mainly on the lithology and structure of the rocks.

The water table at most places in the upper Eocene limestone of Morne Hôpital must be far beneath the surface and wells sunk there would have to be very deep. There is no impervious cover to confine the ground water under pressure and flowing water is not to be expected.

The coarser and more porous beds of Miocene age probably contain water that may be at some places under artesian pressure due to confining beds of marl or silty sandstone, but the Miocene beds are complexly folded and somewhat faulted, so that any such favorable localities could be predetermined only from a very thorough knowledge of their structure, which can not be observed at the surface because the beds are at most places covered by younger rocks. Any attempt to reach artesian water in these beds would be entirely unwarranted. The only well drilled in the Miocene beds (No. 10, p. 525) penetrated no water-bearing beds and was dry. The location of this well, however, is manifestly unfavorable.

The Pleistocene conglomerate is very porous and should contain water at or a little above sea level in localities where it extends downward to that depth. At many places the formation is only a thin cap overlying Eocene or Miocene rocks and at such places it is probably dry. There is little if any possibility of obtaining flowing water from this conglomerate.

The alluvium should yield some water either from shallow or deep wells, but deep wells sunk near the sea would probably be salty, and shallow wells would almost certainly be badly contaminated by sewage in this thickly inhabited region, so that their water would not be fit for domestic use.

There are flowing wells on the Cul-de-Sac Plain, but, as stated on pages 526-527, it appears that flows are not likely to be obtained nearer to

Port-au-Prince than the latitude of Croix-des-Missions and that the head of all such flowing wells in the plain will be insufficient to supply water by gravity to any but the lower parts of Port-au-Prince.

Quality of Water and Treatment for Hardness.

The water used in Port-au-Prince has an agreeable taste and is generally considered good for domestic use. It is not polluted at the springs that furnish the supply, but it is or may be polluted at unprotected breaks in conduits and at poorly covered manholes or through carelessness of workmen making repairs. Chemical analyses of water from Plaisance and Turgeau springs were made by the United States Geological Survey in 1919. (See p. 543.) Presumably these analyses represent fairly well the mineral content of the entire supply, as all the springs are fed mainly by water that has traversed the upper Eocene limestone. The chief feature of the water is hardness in the form of calcium bicarbonate, which makes up more than three-fourths of all the dissolved solids.

Calcium carbonate itself is only slightly soluble in water, but when water containing it takes up carbon dioxide from the atmosphere or the soil the combination is likely to form calcium bicarbonate [$Ca(HCO_3)_2$], which is highly soluble. This reaction produces the considerable quantity of calcium bicarbonate found in most of the waters of the Republic. Calcium bicarbonate is an unstable compound, which readily breaks up on a change of conditions, such as an increase of temperature, which causes the water to lose its carbon dioxide and thereby its power to hold in solution the carbonate, which is precipitated. The water of Port-au-Prince probably loses its carbon dioxide partly because the temperature of the air, especially during the day, is greater than that of the fresh spring water and partly because it is so greatly aerated in passing through pipes that are only partly full and in tumbling through numerous manholes, in which it is violently agitated. The result is that calcium carbonate is precipitated in aqueducts and water pipes so abundantly and rapidly as to obstruct small pipes seriously in a few years.

Hardness in waters can be treated in several ways. Most of the bicarbonate can be removed by heating, which drives off the excess carbon dioxide and causes the precipitation of calcium carbonate. Filtration to remove the precipitate is necessary if the water is to be used within a few hours. This method of treatment is too expensive for a city supply. Bicarbonate and carbonate hardness can be entirely removed by what is generally known as the zeolite process. By this process the water is forced through a mass of specially prepared sodium-aluminum silicate and its calcium and magnesium are exchanged for sodium. This process also is not well adapted to the treatment of large city supplies.

The commonest method of softening water is that which is known generally as the lime-soda process. The added lime reacts with the bicarbonate, converting it all to carbonate and causing most of it to be precipitated. The soda converts other calcium salts, such as sulphate, to carbonate and promotes their precipitation. This precipitate, however, requires many hours, sometimes even days, to settle, and filtration of some kind is usually resorted to instead of complete settling. The process may be either intermittent or continuous. The continuous plants are much more compact but are more difficult to operate successfully. Several such plants in the United States treat successfully from one to five million liters of water a day for industrial use.

No cheap process of softening the water of Port-au-Prince appears to be available. At least two separate plants would be required, one for the combined water of Turgeau and Plaisance springs, the other for the water of Diquini, Chaudeau, and Le Clerc. Large reservoirs would be needed for treating the water and removing the bulk of the precipitate, and filtration through sand would be necessary to remove traces of precipitate that otherwise would be carried over and deposited in the mains as now. The filter beds would require frequent renewal. Such a plant might cost $50,000 to $100,000, and its operation would cost several thousand dollars a year.

As has already been stated (p. 575), the present distributing system is much to blame for the formation of the precipitate; if it could be repaired so that the water would be kept under pressure in air-tight mains not nearly so much precipitate would be formed.

Although the softening of the entire supply of Port-au-Prince does not seem practicable, the softening not only of the water of that city but of most other waters of the Republic on a small scale for use in steam boilers, laundries, and other industrial plants would probably be economical. Many firms make a special business of installing effective plants for such treatment of water. For small steam boilers the use of suitable boiler compounds or the simple addition of a little sodium carbonate to the feed water would be helpful. This treatment does not prevent precipitation in boilers, but the precipitated material can usually be blown out before it forms scale.

SURFACE WATER.

Tippenhauer[1] has suggested that an adequate surface supply for Port-au-Prince could be obtained by constructing a tunnel to direct the Grande Rivière de Léogane into Rivière Froide at the locality where the two streams are separated by a narrow ridge near Croix Imbert. Probably this scheme is feasible, but it would be very expensive and would involve an entire reconstruction of the present distributing system. Surface water supplies have many advantages, however, and a survey of the project with an estimate of cost might be justified. Measurements of the flow of the

[1] Tippenhauer, L. Gentil, Beiträge zur Geologie Haitis: Petermanns Mitt., Band 47, p. 177, 1901.

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.