A Brief Appraisal of Ground-Water Conditions in the Coastal Artesian Basin of British Guiana, South America

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1663–B

Prepared in cooperation with the Geological Survey Department of British Guiana and under the auspices of the United States Operations Mission to British Guiana

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By G. F. WORTS, JR

CONTRIBUTIONS TO HYDROLOGY OF LATIN AMERICA AND THE ANTILLES

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A BRIEF APPRAISAL OF GROUND-WATER CONDITIONS IN THE COASTAL ARTESIAN BASIN OF BRITISH GUIANA, SOUTH AMERICA

By G. F. Worts, Jr.

ABSTRACT

The coastal artesian basin of British Guiana covers an area of about 7,000 square miles; it is bordered on the north by the Atlantic Ocean and on the east by the Courantyne River and Surinam (Dutch Guiana), and extends westward to the Pomeroon River. The southern edge of the basin is formed by outcrops of the basement system and extends inland from the coast as much as 100 miles. The seaward fringe of the coastal plain, averaging about 5 miles in width, contains virtually all the agricultural development in the Colony and supports approximately 90 percent of the total population of 450,000.

The White Sand series of Pliocene(?) and Pleistocene age, which is the principal water-bearing deposit in the coastal basin, is slightly deformed and rests unconformably on the Berbice formation and the basement system. Along the coast it contains an upper sand aquifer, ranging in thickness from 50 to 300 feet, in which brackish to saline ground water is confined beneath the Demerara clay of probable Recent age. More than 75 flowing wells, 100 to 300 feet deep, obtained their supply from this source in the period 1831–1915. In 1913 a deeper artesian aquifer, the "A" sand, was tapped, and in 1957 about 200 flowing wells obtained water of reasonably good chemical quality from this source. The "A" sand ranges in thickness from 40 to 100 feet, and its depth increases progressively southeastward from about 250 feet near the Pomeroon River to about 900 feet in the reach between New Amsterdam and the Courantyne River. Pumping tests made in Georgetown indicate that the "A" sand aquifer coefficients are: transmissibility 180,000 gallons per day per foot and storage 0.0002. Well data near Georgetown and New Amsterdam indicate the existence of an undeveloped aquifer several hundred feet beneath the "A" sand aquifer. The maximum known thickness of the White Sand series is about 5,000 feet, encountered in an oil-test hole near New Amsterdam. The lowermost 2,000 feet contains saline water.

Recharge to the coastal artesian baisn from precipitation and runoff occurs in the 5,000-square mile outcrop area of the White Sand series where rainfall averages about 100 inches a year. Ground water moves northward from the recharge area beneath the confining clays of the Coropina formation, Demerara clay, and clay strata within the White Sand series, and is discharged in small part by upward leakage, but presumably the bulk of the natural discharge is submarine.

In 1956 the combined yield of the 200 flowing wells tapping the "A" sand was roughly 20,000 Igpm (Imperial gallons per minute), about 5,000 Igpm less than

the initial combined yield. The decrease has been accompanied by an apparent average head decline in 30 years of 3 to 4 feet and has caused concern by the Government as to whether the supply was being exausted. This study indicated that the decline in head and flow was due principally to mutual interference between wells and not to depletion of the supply. However, the decline in head along the coast may result in sea-water intrusion at some time in the future. Pumping of the coastal wells is considered undesirable, principally because the threat of sea-water intrusion would be increased.

INTRODUCTION

PURPOSE AND SCOPE

As a result of requests by the Government of British Guiana to the International Cooperation Administration, United States Department of State, arrangements were made for a hydrologist from the U.S. Geological Survey to undertake a reconnaissance of the needs for ground-water investigations of the coastal artesian basin of British Guiana. The Government of British Guiana was concerned about the apparent drop in artesian pressure in existing wells and desired advice on the collection and recording of data needed for evaluating the potential yield of the artesian aquifers and the possible need for conservation of the water resources of the coastal basin. The potential water supply is critical to the future planning of land development and settlement along the coast, where 90 percent of the population of the Colony now lives.

Field work undertaken during the early part of 1957 included land and air reconnaissance of the coastal artesian basin, inspection of numerous wells, and observation of methods of measuring artesian head and well discharge. An automatic water-level recorder was installed and operated on the Subryanville well for a week to observe changes in hydrostatic head caused by tidal loading. The instrument was moved to Shelter Belt well 2, and operated for 2 weeks, then to the Campbelville well for 1 week to make pumping tests to estimate aquifer constants. All three wells are in Georgetown. A microbarograph was operated during the period of these tests.

Nearly all the available basic water data were inspected at the offices of the Pure Water Supply Scheme, the Geological Survey Department, the Drainage and Irrigation Department, the Transport and Harbours Department, and the Meteorological Laboratory. Records of artesian head, well discharge, specific capacity, and chemical analyses for about 200 wells were compiled and summarized. Drillers' logs of wells were studied, records of streamflow were collected, and offshore information was compiled. The available reports on the geology and hydrology of the coastal artesian basin were studied and summarized.

This report briefly summarizes the meteorological data, the geologic features of the coastal sediments, the ground-water conditions, the quality of water, and steamflow records. The report also discusses the apparent decline in pressure head in the artesian wells, and presents preliminary coefficients of transmissibility, field permeability, and storage of the so-called "A" sand unit of the White Sand series. A separate report (Worts, 1958) proposes methods of data collection and study for future water-resources investigations in the coastal basin.

LOCATION AND GENERAL FEATURES OF THE AREA

British Guiana is on the northeast coast of South America approximately between lat 1° and 9° N. and long 57° and 61° W. and covers an area of about 83,000 square miles. It is bordered on the east by Surinam (Dutch Guiana), on the south by Brazil, on the west by Brazil and Venezuela, and on the north by the Altantic Ocean (pl. 1). The Colony lies between the mouths of two large South American Rivers—the Amazon to the east and the Orinoco to the west. The North Equatorial Current flows west-northwestward along the coast and enters the Caribbean Sea between the Leeward and Windward Islands, which are about 300 miles northwest of the Colony. The largest city in British Guiana is Georgetown, the capital, which is on the coast at the mouth of the Demerara River and which reportedly has a population of about 80,000.

The principal coastal streams, from east to west, are the Courantyne, Canje, Berbice, Abary, Mahaicony, Mahaica, Demerara, Essequibo, Pomeroon, Waini, and Barima Rivers. In general, the major drainage basins coincide with the political subdivisions of the country. On the east the County of Berbice includes the drainage areas of the Berbice, Abary, and Canje Rivers and the western tributary area of the Courantyane River. The small County of Demerara includes the drainage areas of the Demerara, Mahaica, and Mahaicony Rivers. The County of Essequibo includes the drainage area of the Pomeroon River and the coastal part of the Essequibo River. The Counties of Rupununi, Mazaruni–Potaro, and Northwest lie outside the coastal basin.

The coastal artesian basin, with which this report is concerned, extends from the Courantyne River on the east to the Barima River on the west. Because there is little development and meager data in the western part of the basin, the analysis of the data and proposals in this report are limited to the area between the Courantyne and Pomeroon Rivers—a distance of about 150 miles. In general the inland extent of the coastal basin is the contact between the White Sand series and the basement system (pl. 1), which is only about 5 miles from the coast near the Essequibo River, about 50 miles near Mackenzie, a maximum of 100 miles near Kwakwani, and 60 miles from the coast near Orealla on the Courantyne River. The total area of the basin is about 7,000 square miles. Of this total the coastal plain occupies approximately 2,000 square miles.

The seaward fring of the coastal plain, averaging about 5 miles in width, contains virtually all the agricultural development in British Guiana, and supports approximately 90 percent of the total population of about 450,000. This coastal fringe has been subdivided into 14 local areas which are in common usage in the Colony (table 1) and to which extensive reference is made in this report.

TABLE 1.—*Coastal areas of British Guiana*

Area	*General extent (pl. 1)*
Essequibo Coast	Charity to Spring Garden.
Wakenaam Island	Mouth of Essequibo River.
Leguan Island	Do.
East Bank Essequibo	Mora to De Kinderen.
West Coast Demerara	De Kinderen to Vreed en Hoop.
West Bank Demerara	Vreed en Hoop to Wales.
East Bank Demerara	Craig to near Georgetown.
Georgetown	Mouth of Demerara River.
East Coast Demerara	Near Georgetown to Abary River.
West Coast Berbice	Abary River to Rosignol.
West Bank Berbice	Resignol to 5 miles south.
East Bank Berbice	Mara to New Amsterdam.
Canje-Berbice	Mouth of Canje River to 5 miles upstream.
Courantyne Coast	Mouth of Berbice River to Crabwood Creek.

Except for a few artesian wells near Hyde Park on the Demerara River and at Morawhanna near the Venezuelan border, all the existing 200 deep artesian wells are in the 14 areas listed in table 1. These wells are used wholly for public supply and none are equipped with pumps. The wells and related distribution lines are constructed and maintained by the Government of British Guiana.

The city of Georgetown obtains the bulk of its supply from surface sources and only a small amount from artesian wells. The city uses about 5 million Igpd (Imperial gallons per day).[1] The Georgetown Water Works has coagulation, filtration, and chlorination equipment and provides the town with an ample supply of potable water. It is understood that the present equipment can furnish as much as 9 million Igpd.

One of the principal problems in the Colony is transportation. An inadequate system of roads extends along the coast and no roads lead into the interior; railroads are old and of limited extent; and river boats, though slow, provide adequate service in the navigable parts of the principal streams and along the coasts, and provide ferry service for vehicles and passengers across the mouths of the Courantyne, Berbice, Demerara, and Essequibo Rivers, where no bridges exist. The silt and clay bars at shallow depth along the coast make shipping by ocean

[1] One Imperial gallon equals 1.2 U.S. gallons.

vessels a difficult problem. Atkinson Field, about 25 miles south of Georgetown and near Hyde Park, is the only commercial airport for international carriers.

The principal agricultural products of the Colony are sugar and rice. Twelve sugar estates grind and process raw sugar for export. Table 2, compiled from a report by Blaich (1954), shows the acreage of crops, nearly all of which are irrigated by surface water, for the period 1942–52. The water applied for sugar and rice reportedly is about 7 and 3 feet per acre per crop, respectively. One crop of sugar cane and two crops of rice per year usually are grown.

Mining constitutes the only other principal industry. Bauxite ore, mined principally by the Demerara Bauxite Co. at Mackenzie and by the Reynolds Aluminum Co. at Kwakwani, is the principal export. Gold and diamonds, derived largely from placer operations in the streams draining the Pakaraima Mountains, are found in limited quantity.

TABLE 2.—*Crop acreage in the coastal plain, 1942–52*

[Unpublished data from British Guiana Department of Agriculture]

Crop	Acres		
	1942–46 Average	1947–51 Average	1952
Sugar cane	67, 800	69, 900	81, 900
Rice:			
Spring	16, 500	15, 100	19, 100
Autumn	79, 600	94, 100	134, 000
Cocoanuts	32, 100	33, 100	31, 500
Fruit	5, 300	7, 400	8, 000
Vegetables	21, 200	20, 000	21, 400
Coffee	3, 300	3, 600	4, 200
Cocca	400	900	1, 200
Rubber	2, 000	1, 900	1, 800
Maize	1, 000	----------	1, 600
Total	229, 200	246, 000	304, 700

RESPONSIBILITY FOR WATER-SUPPLY DEVELOPMENT

The Pure Water Supply Scheme of the Public Works Department and the Drainage and Irrigation Department are responsible for the development and maintenance of ground-water and surface-water supplies, respectively. In addition, the cities of Georgetown and New Amsterdam operate their own water-supply systems, but they are dependent to a moderate degree upon the two Government agencies for the construction and maintenance of artesian wells and surface reservoir facilities.

The Pure Water Supply Scheme drills and maintains wells in the Colony. In addition the agency installs and maintains pipelines which lead from the wells and extend along the coast highway and

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local roads. The pipelines have faucets or taps every few hundred yards to provide for a public supply. The spacing of the artesian wells along the coast averages one per mile, although locally wells are several miles apart. The unusual feature of this rural water-supply system is that the cost of construction and maintenance of wells and distribution lines is not charged to the communities.

The Drainage and Irrigation Department provides and maintains the facilities for the irrigation of crops, flood control, stream gaging, and drainage of the low coastal plain, which near the coast is below sea level at high tide. Between 5 and 10 miles inland and between the principal rivers, the Department has constructed or is planning to construct dual-purpose dams or dikes for flood control and irrigation. Because of the extremely gentle seaward slope of the plain, the dams need be only 6 to 8 feet in height to provide a shallow large-capacity reservoir space that extends inland many miles. The structures and reservoirs are called water conservancies. Completed works include the East Demerara (Lamaha) Water Conservancy, covering about 150 square miles between the Demerara and Mahaica Rivers, which is the principal source of water supply for Georgetown; and the Tapakuma and Capoey Water Conservancies on the Essequibo Coast (table 1), which reportedly supply water largely for the irrigation of rice. Those under construction and planned include the Boerasirie between the Essequibo and Demerara Rivers, several conservancies between the Mahaica and Berbice Rivers, and one between the Berbice and Courantyne Rivers. In swampy areas where no conservancies exist a series of "back dams" are used to retain water for irrigation. The reported total yield of all the planned and completed water conservancies will average considerably more than 1 million acre-feet a year.

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Assistance in the collection of geologic data was furnished by Mr. David Bleackley, Geologist of the British Guiana Geological Survey. Mr. C. S. Burrowes, Superintendent, Pure Water Supply Scheme, Public Works Department, made available all records of wells and provided the necessary assistance in the installation and operation of

an automatic water-level recorder; Mr. H. R. Bentley, Chief Engineer, Georgetown Water Works, cooperated on the pumping test made at the city wells; Mr. J. E. Isaacs, Meteorological Observer, Department of Agriculture, supplied climatic data for the Colony; and Mr. C. S. Ridley, Assistant Director, and Mr. W. E. Ying, Superintendent of Surveys, Drainage and Irrigation Department, furnished information on stream discharge and water conservancies. Office space, working facilities, and transportation were kindly supplied by the British Guiana Geological Survey and the Pure Water Supply Scheme.

Excellent cooperation was received from the officers of the United States Consulate in Georgetown. Mr. A. J. Cope, Jr., Consul, and Mr. M. D. Green, Administrative Officer, International Cooperation Administration, made the necessary arrangements for the conduct of the work.

PREVIOUS INVESTIGATIONS

The general geology of British Guiana has been described in an old report by Brown and Sawkins (1875) and more recently in reports by Bracewell (1948) and Stockley (1955). The geology shown on plate 1 is after Stockley (1954). The geology of the unconsolidated coastal deposits is presented in a report by Grantham and Noel-Paton (1937) which establishes general stratigraphic units as determined from the logs of artesian wells drilled in the coastal artesian basin, and contains an appendix of 78 drillers' logs and an appendix of well-sample classifications.

The only publication that presents an areal study of both the geologic and hydrologic features of the coastal artesian basin is by Bleackley (1956). That bulletin describes the stratigraphy and lithology of the sediments, the decline in artesian head, the effect of tidal loading on the pressure head and flow of wells, the history of artesian well drilling, and a brief inventory of ground-water sources, including comments and limited quantitative data on evapotranspiration and infiltration of rain and runoff.

A series of reports on the wells in the coastal plain was prepared by Prof. Harrison (1913, 1914a, 1914b, 1923), and Harrison and Buck (1919). These brief papers give detailed accounts of the drilling of the first two deep artesian wells in Georgetown in 1913 and 1914 (1914a and 1914b); they present data on old shallow wells drilled prior to 1913 (1913) and describe the choking of some of the first 28 deep artesian wells drilled between 1913 and 1918 (1919, 1923).

In 1941 the Trinidad Leaseholds Co., Ltd., drilled a test hole at Rose Hall, 5 miles east of New Amsterdam, to a depth of 6,456 feet. The test hole penetrated the full sequence of sedimentary rocks and bottomed in the basement system. Before drilling, a seismic survey was made of the coastal sediments between Georgetown and the

Courantyne River. The results of the test hole and the seismic survey are incorporated in a report by Kugler and others (1944).

A report by Ijzerman (1931) on the geology of Surinam contains useful information on the coastal deposits that extend from the Courantyne River eastward in a narrowing coastal belt across the Colony to French Guiana.

CLIMATE

The tropical climate of British Guiana is characterized by two wet and two dry seasons, a refreshing northeast trade wind, moderately warm temperatures, and abundant rainfall. Table 3 shows the coastal rainfall by counties, as obtained from the annual meteorological report by Isaacs (1956).

The average annual rainfall increases from about 80 inches in the eastern part of the coastal plain to about 100 inches in the western part. Inland the rainfall is somewhat greater. There are four seasons: a moderately wet season, December and January; a moderately dry season, February through April; the principal wet season, May through August; and the principal dry season, September through November.

The annual temperature range at the coast is small. For the 108-year period 1846–1954 the mean annual temperature was about 80° F, mean maximum about 85°, and mean minimum 76°. The prevailing winds are from the northeast and east; average monthly velocities range from 3 to 6 knots and average nearly 5 knots. The average humidity in Georgetown ranges between 70 and 80 percent during the dry seasons and between 80 and 90 percent during the wet seasons.

TABLE 3.—*Average rainfall, in inches by counties, at coastal stations of British Guiana, 1890–1955*

[Data from Isaacs (1956, table 17)]

Month	County			Average, all stations
	Berbice	Demerara	Essequibo	
January	7.74	8.22	9.66	8.67
February	5.62	5.66	5.85	5.69
March	6.07	6.04	6.16	6.10
April	7.05	6.72	6.46	6.74
May	10.89	10.44	12.84	11.39
June	11.14	13.12	13.74	13.58
July	9.56	10.77	11.03	10.46
August	6.15	6.65	7.43	6.79
September	2.32	3.10	3.65	3.03
October	2.23	2.97	4.29	3.16
November	3.24	5.71	7.18	5.37
December	8.77	12.06	13.18	11.31
Total	80.78	91.36	101.47	92.29

SUMMARY OF GEOLOGY

PHYSIOGRAPHY

The principal physiographic features that relate to ground water in the coastal artesian basin are the coastal plain, the adjacent uplands, the major rivers, and the continental shelf. The geomorphology of the coastal plain is described in a recent report by Bleackley (1957), which in large part has been drawn upon in the preparation of the following paragraphs.

Between the Pomeroon and Courantyne Rivers the coastal plain ranges in width from 5 miles near the Essequibo River to about 50 miles near the Berbice River; it extends along the coast for about 150 miles and covers an area of nearly 2,000 square miles (pl. 1). The seaward one-half to two-thirds of the plain is underlain by the Demerara clay, the surface of which has been termed the Young Coastal Plain; the remainder is underlain by the Coropina formation (largely clay), the somewhat dissected surface of which has been termed the Old Coastal Plain. The two units are not distinguished on the geologic map but are shown collectively as the coastal sediments (pl. 1).

The altitude of the plain along the coast reportedly ranges from less than 1 foot to about 3 feet above mean sea level; it rises inland to a maximum of 8 to 10 feet where underlain by the Demerara clay and to a maximum of about 25 feet where underlain by the Coropina formation. An extensive system of sea walls, called sea defenses, which extend along the coast and inland along the banks of rivers for 5 to 10 miles, prevents the high tides, which rise 3 to 5 feet above mean sea level, from flooding the coastal plain. However, there are numerous areas where the sea defenses are lacking, and hence the areas are flooded at high tide. Manually operated gates, called "kokers," are maintained at intervals along the sea defenses to provide outlets to the sea for drains that convey flood water, swamp water from inland areas, irrigation tail waste, and probably rising ground water. The gates are closed at high tide to keep out the sea water and opened at low tide to permit the accumulated water to discharge to the ocean. However, during periods of heavy rainfall, the coastal areas become flooded despite the numerous drainage work.

Other superficial features of the coastal plain include the stranded beach ridges, sand spits, bars, and levees that locally occupy a strip 5 to 10 miles in width immediately behind the present shore and locally adjacent to the large rivers (Bleackley, 1957).

The uplands bordering the coastal plain on the south are of gentle relief and are underlain by the White Sand series. The altitude of the uplands increases from 35 to 45 feet at the north, where a well-defined terrace level is evident, to more than 400 feet to the south.

The major coastal streams are tidal for considerable distances inland; in most the tidal effects extend to the first rapids or falls. The Essequibo River is tidal for at least 60 miles upstream from its mouth, and the other rivers are tidal for distances of 30 to at least 50 miles inland. The depth of the major rivers range from 10 to 25 feet, and the Courantyne, Berbice, Demerara, and Essequibo Rivers are navigable for distances of 50 miles or more from the coast.

The Continental Shelf slopes gently seaward, reaching a depth of 50 fathoms at an average distance of 75 miles and 100 fathoms at about 85 miles; the ocean floor then deepens rapidly to 500 fathoms in less than 5 more miles. Thus, when plotted in profile, the scattered soundings given on Admiralty Hydrographic Chart 1801 suggest that the edge of the Continental Shelf averages about 75 miles offshore at a depth of roughly 50 fathoms, or 300 feet.

GENERAL STRATIGRAPHY

The stratigraphy of the coastal artesian basin of British Guiana has been described in considerable detail by Grantham and Noel-Paton (1937), Kugler and others (1944), and Bleackley (1956, 1957). A review of the status of geologic knowledge, however, reveals that considerable subsurface study and exploration are needed to determine the stratigraphic position of the several sedimentary units and their relation to the occurrence of ground water. Four sedimentary units have been described by Bleackley (1956) as constituting the coastal artesian basin. The basin is underlain at depth and bounded on the south by rocks of the basement system. The seismic survey and the Rose Hall test hole (Kugler and others, 1944) provide the only information on the configuration of the basement system southeast of Georgetown, on the stratigraphy at a depth greater than about 1,600 feet, and on the depth to the basal saline water. The Rose Hall test hole, 5-miles east of New Amsterdam, penetrated rocks of the basement system at a depth of about 6,300 feet, but the seismic survey suggests that the maximum depth to the east along the coast may be 7,300 feet. The stratigraphic units and their general relationship and water-bearing properties are shown in the geologic table.

BASEMENT SYSTEM

The rocks of the basement system probably are Precambrian in age and consist principally of gneiss, granite, and volcanic schist. The contact between the basement system and the White Sand series (pl. 1) forms the southern end of the groundwater basin. From the Essequibo River northwestward the contact is within 10 miles of the coast, and there the coastal basin is narrow. Furthermore, the basement system underlies the basin at relatively shallow depth—300 feet

Stratigraphic units of the coastal plain

[In large part after Bleackley, 1956]

Geologic age			Stratigraphic unit	Thickness (feet)	General lithologic character	Water-bearing properties
Cenozoic	Quaternary	Recent	Demerara clay	100±	Soft, blue, gray, and brown clay, locally mottled, rarely silty; has high water content.	Yields no water to wells. Together with Coropina formation confines water in underlying White Sand series.
			—Local unconformity—			
		Pleistocene	Coropina formation	50±	Firm, compacted, red, purple, and yellow mottled clay having low water content.	Yields no water to wells. Together with Demerara clay confines water in underlying White Sand series.
			—Unconformity—			
	--?--	-------?-------	White Sand series	5,000±	Subdivisions of Bleackley (1956): (a) Upper sand series, 50 to 300 ft thick, largely angular to subangular quartz sand; (b) intermediate clay series; clay and shale, lenses of quartz sand; (c) "A" sand, averaging 40 to 90 feet thick; largely angular and subangular quartz sand and fine gravel; (d) alternating beds of sand and clay.	1. Upper sand series: artesian head above land surface, saline or brackish near coast; not used as water source for many years. 2. Intermediate clay: not a source of supply; confines water in "A" sand. 3. "A" sand; principal source of artesian water along coast. 4. Alternating sand and clay: not tapped by wells, but upper sand beds probably would provide artesian supply to wells; saline in lower part.
	Tertiary(?)	Pliocene				
			—Major unconformity—			
Mesozoic(?)			Berbice formation	1,200±	Bleackley (1956) limits Berbice to conglomerate, sandstone, shale intervening between White Sand series and underlying basement system. Does not crop out.	Might yield water locally, but contains saline water in Rose Hall test hole.
			—Major unconformity—			
Precambrian(?)			Basement system		Principally gneiss, granite, and schist; locally includes bauxite deposits.	Consolidated; would yield little or no water to wells, except small amounts where fractured, jointed, or deeply weathered.

in water wells at the mouth of the Essequibo River and 400 feet near the Pomeroon River. From the east bank of the Essequibo River the contact trends south-southeastward to near Kwakwani where it turns eastward, possibly beneath a thin section of the White Sand series, past Orealla, and thence into Surinam.

From the Essequibo River southeastward along the coast, water wells encounter the basement system at gradually increasing depth, reaching about 850 feet in a well at Vreed en Hoop on the Demerara River (pl. 1). Across the river in Georgetown wells as much as 1,600-feet deep have not penetrated bedrock. Bleackley (1956, fig. 3) postulates a major normal fault beneath the river to explain the offset in basement. Southeast of Georgetown the surface on the basement system is shown by Kugler and others (1944, fig. 1) to become progressively deeper, to reach a maximum depth of 7,300 feet near New Amsterdam, then to rise perceptibly to about 6,000 feet beneath the mouth of the Courantyne River. The slope of the basement surface, as defined by the seismic survey, depicts a broad seaward-plunging trough whose axis lies approximately beneath the Berbice River.

The bottom of the coastal artesian basin is considered to be the basement system, except where the basal saline water occurs at shallower depth. A study of the electric log for the Rose Hall test hole shows that saline water occurs below a depth of about 3,100 feet. So far as could be determined, no water wells have been drilled sufficiently deep to encounter the basal saline water. Thus, its depth elsewhere in the basin remains unknown.

For the practical purposes of water-supply development, the basement system, even where it is in contact with deposits bearing fresh water, is considered to be a poor prospect. This point is emphasized, because a consulting firm once proposed that deep wells be drilled through the productive White Sand series to search for permeable fracture systems in the underlying basement rocks. Such exploration would be costly, and the possibility of obtaining an amply supply of water from this source is doubtful.

BERBICE FORMATION

The Berbice formation of Mesozoic(?) age was proposed by Kugler and others (1944) to include the 6,200 feet of sediments penetrated between the Demerara clay and the basement system in the Rose Hall test hole. Subsequently, Bleackley (1956) proposed that the Berbice formation be restricted to the lowermost 1,200 feet of consolidated sedimentary rocks, largely conglomerate, sandstone, and shale of possible Mesozoic age; he also proposed that the White Sand series described by Grantham and Noel-Paton (1937) be accepted for the upper part of the sediments which overlie the restricted Berbice formation and extend upward to the base of the Demerara clay.

The Berbice formation of Bleackley (1956) is known only from the Rose Hall test hole and has no known surface outcrop. It presumably pinches out southward against the generally north-plunging surface of the basement system; northward out to sea it probably thickens.

Because the basal saline water was found at a depth of about 3,100 feet in the test hole, the possibility of obtaining a potable supply from the Berbice formation, even if the beds should prove productive, is remote—at least in the vicinity of New Amsterdam.

WHITE SAND SERIES

Along the coast the uppermost 1,500 feet of the White Sand series has been drilled extensively for the so-called deep artesian source of ground-water supply. This source was first discovered through the efforts of Harrison (1914a) in 1913 when the old D'Urban Park well in Georgetown was drilled and completed to a depth of 561 feet. In 1936, after more than 80 deep wells had been drilled along the coast, Grantham and Nole-Paton (1937) described the deposits penetrated and established five units or members, of which the Demerara clay and possibly the Coropina formation were included as the "upper clay series." The underlying members were termed, successively: "upper sand series," "intermediate clay series," "the 'A' sand" (the principal producing horizon for the deep artesian wells), "lower clay series," and "lower sand series."

Bleackley (1956, 1957) assigned the White Sand series to the deposits of Pliocene(?) and Pleistocene age that are beneath the Demerara clay and the Coropina formation and above the Berbice formation—a total thickness of nearly 5,000 feet at the Rose Hall test hole. He subdivided the series as follows: "upper sand series," "intermediate clay series," "lower or 'A' sands," and "alternating sands and clays" (corresponds to lower clay and lower sand series of Grantham and Noel-Paton).

The upper sand series underlies the Demerara clay at an average depth of 150 feet along the coast. It increases in thickness from about 50 feet near the Pomeroon River to about 300 feet near New Amsterdam; southeastward toward the Courantyne River its base is difficult to distinguish from the underlying intermediate clay series (Bleackley, 1956). The upper sand is composed mainly of angular and subangular quartz grains, and Harrison (1914b) states that beneath Georgetown the unit is composed of dune sand containing numerous small fragments of decomposed wood and resting on a former land surface at a depth of about 260 feet. Ground water in the upper sand is confined beneath the Demerara clay and for the most part is moderately saline near the coast; it may be fresh inland.

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The intermediate clay comprises clay and shale, which include lenses of white kaolinitic clay, and lenses of unconsolidated quartz sand. This unit forms the aquiclude that overlies the "A" sand.

The "A" sand is the principal source of the artesian water that supplies most of the communities along the coast. The unit is composed of angular to subangular quartz sand and fine gravel. Table 4 shows the average depth range and thickness of the "A" sand for the coastal areas, as determined from the logs of 186 wells.

Table 4 shows that the "A" sand generally increases in thickness and depth southeastward from the Essequibo Coast to West Coast Berbice, and that it may decrease somewhat toward the Courantyne Coast. This broad synclinal feature conforms to the surface of the basement system described by Kugler and others (1944).

TABLE 4.—*Average depth range and thickness of the "A" sand in 186 wells along the coast*

[Compiled from records of the Pure Water Supply Scheme]

Area (table 1)	Wells	Depth range in wells (feet)			Average thickness (feet)
		Maximum	Minimum	Average	
Essequibo Coast	16	361–386	177–229	270–310	40
Wakenaam Island	7	282–334	224–300	255–300	45
Leguan Island	8	330–400	226–319	285–340	55
East Bank Essequibo	5	436–484	266–281	360–400	40
West Coast Demerara	16	700–723	367–419	510–570	60
West Bank Demerara	15	598–654	421–474	500–550	50
East Bank Demerara	18	642–683	366–477	500–570	70
Georgetown	10	676–790	543–587	640–720	80
East Coast Demerara	35	736–978	626–671	740–820	80
West Coast Berbice	13	1,141–1,186	794–892	940–1,000	60
West Bank Berbice	4	947–976	782–827	870–910	40
East Bank Berbice	6	957–1,120	790–832	890–960	70
Canje-Berbice	7	948–971	746–943	850–940	90
Courantyne Coast	26	1,470–1,505	578–623	930–990	60

Several hundred feet below the base of the "A" sand, in the alternating sand and clay unit (see geologic table, p. 11), three wells found a deeper sand bed that warrants exploration as an additional source of artesian water supply. The drillers' logs and electric logs of the Rose Hall test hole near New Amsterdam and the new D'Urban Park well and Shelter Belt well 1 in Georgetown show that in each a deeper sand was penetrated between about 1,400 and 1,700 feet, 1,320 and 1,385 feet, and 1,250 and 1,310+ feet in the three wells, respectively. The two wells in Georgetown probably found the same sand, but the sand in the Rose Hall test hole, some 60 miles to the southeast, may not be the same stratum even though its stratigraphic position with respect to the "A" sand is similar at both sites. The print of the electric log for the new D'Urban Park well bears the following notation beside the indication of the deeper sand: "Good commercial fresh-water saturation; formation pressure higher than in the upper producing zone."

The electric logs show also that below the base of the "A" sand the section contains numerous cemented beds 5 to 20 feet thick. These are indicated on the log by a high resistivity and a very low SP (self-potential). The drillers' logs, which in general agree very closely with the electric logs, describe these beds as "very hard sand," "very hard shale," and in some instances "very hard drilling, no sample." The cemented beds between the "A" sand and the deeper, undeveloped sand aquifer should provide an effective aquiclude, and leakage between the aquifers probably would be small to negligible. Although the head in the deeper aquifer may be higher than that in the "A" sand, the yield per foot of drawdown (specific capacity) may be less, largely because the deeper aquifer is somewhat thinner.

COROPINA FORMATION AND DEMERARA CLAY

The Coropina formation and Demerara clay were mapped as undifferentiated coastal sediments (pl. 1). At the coast the subsurface relation of these two units is not known, but together they form the uppermost clay, which has an average thickness of 150 feet and which rests, probably unconformable, on the White Sand series.

Where exposed on the coastal plain the Coropina formation intervenes between the exposures of Demerara clay and the White Sand series and forms a surface of low relief 10 to 25 feet above mean sea level. It is characterized by a poorly integrated and complex drainage pattern and is composed principally of firm compacted red, purple, and yellow mottled silty clay having a relatively low water content. Its age may be Pleistocene.

The Demerara clay underlies the seaward one-half to two-thirds of the coastal plain and presumably extends offshore a considerable distance. It is composed of soft, blue, gray, and brown clay that is locally mottled, rarely silty, occasionally gritty and that has a relatively high water content. Its surface is characterized by large swamps (about 80 percent of its surface), by a low relief of 1 to 10 feet above mean sea level, and by continued deposition during floods. The clay probably is of Recent age.

The Coropina formation and the Demerara clay confine water in the underlying upper sand of the White Sand series. Several springs are reported to occur in areas underlain by the Demerara clay. The source of the spring water could be the White Sand series or sand lenses contained in the clay unit.

GROUND-WATER FEATURES

The Pure Water Supply Scheme has collected ground-water data since 1913, and the late Sir J. B. Harrison published several papers on well data. The records and reports were inspected, and several weeks were spent in tabulating, summarizing, and briefly analyzing the material. Although certain of the records are fragmentary, sufficient head readings, well-discharge and drawdown tests, and chemical analyses are available, together with the geologic studies already described and reconnaissance field tests made by the author, to provide the basis for a brief analysis of ground-water conditions in the coastal artesian basin of British Guiana.

OCCURRENCE OF GROUND WATER

Ground water is one phase of the complex movement of water in the hydrologic cycle from ocean to air to land, and back to the ocean. This cycle may be complete or may be interrupted at any point, because some of the water that falls on the land surface is used by vegetation, some is evaporated, some runs off in streams and rivers, and some seeps into the ground. When the seepage or recharge reaches the water table, it moves in the direction of the hydraulic gradient, or from points of higher head to points of lower head in areas of natural or artificial discharge.

The coastal artesian basin of British Guiana consists of a recharge or catchment area, which coincides roughly with the exposed area of the White Sand series, and an area of confinement, which is underlain by the Coropina formation and Demerara clay and accordingly has the same extent as the coastal plain. The "A" sand unit is confined by relatively impermeable fine-grained sediments in the overlying intermediate clay unit, the southern extent of which is not known. Similarly, no surface geologic data are available concerning the catchment area of the "A" sand. The bottom of the ground-water basin is at the base of the White Sand series, except where the sediments in the deeper part of the basin contain saline water which forms the lower limit of the usable supply.

Rain and seepage loss from streams in the catchment area replenish the ground-water reservoir. Although there are no well data in the catchment area, it is logical to assume that ground water moves generally northward, a part entering the permeable sections of the White Sand series and a part probably being rejected, at least in the extremely wet seasons of the year, as discharge to creeks and streams along the inland edge of the Coropina formation. The part moving northward in the confined aquifers either is discharged through the artesian wells, or seeps through the confining beds, from which it is subsequently discharged either into streams by flow, by evaporation and transpiration, or as submarine discharge some distance offshore.

All wells completed at depths greater than the base of the Demerara clay are flowing artesian wells. In general, the head in the upper sand unit has ranged from 3 to 5 feet above ground level, but no wells have been completed in this unit for more than 40 years.

The head in the "A" sand in 1954 ranged from 3 to 20 feet above ground level. The yields of wells screened in the "A" sand ranged from a few to nearly 400 Igpm. Former wells screened in the upper sand are termed shallow artesian wells, and wells completed in the "A" sand have been called the deep artesian wells. However, this terminology employing comparatives may cause confusion if still deeper artesian aquifers are developed.

HISTORICAL NOTE ON WELL CONSTRUCTION

A bronze plaque on the southwest corner of the Georgetown museum and library bears the following inscription: "On this site stood Fort St. George, erected in 1781 by Lt. Col. Robert Kingston, first British Governor of Demerary." About 30 feet to the west is a brick-curbed pool about 10 feet in diameter that is the reconstructed remains of the oldest well in the Colony, reportedly dug in 1781 to a depth of 10 to 12 feet.

The first artesian well was drilled in 1831 by a Major Staples at Fort William Frederick in Georgetown (Dalton, 1855, p. 41–43) and was completed at a depth of 123 feet in the upper sand unit of the White Sand series. Egerton and Rodway (1913) presented data on 76 shallow artesian wells, which ranged in depth from 100 to 300 feet and which obtained water from the upper sand. They reported that the quality of water in most of the wells was brackish to saline. The natural flow from these wells ranged from 5 to 70 Igpm (Park, 1910); in general the deeper wells had the larger flows.

After the drought of 1911–12, the Government drilled a deep artesian well in an attempt to develop a supply of potable water. Harrison (1914a, 1914b) has described the construction of the first well, drilled at D'Urban Park in Georgetown in 1913, and the second well, drilled at the Bonded Warehouse in Georgetown in 1914. Both were constructed by the cable-tool, or percussion, method and were completed in the "A" sand at depths of 561 and 669 feet; they had initial flows of about 250 and 300 Igpm, respectively. The deep artesian water proved highly corrosive, and in 1918, after 28 wells had been completed (the first 3 by the cable-tool method and the remainder by the rotary method), Harrison and Buck (1919) described the choking of some and a decrease of flow in most of them. Between 1919 and 1924, while the problem was being studied, no wells were drilled. From 1925 to 1930 various types of brass and steel screens were tried, but few were successful (Park, 1931). In 1931 cement-asbestos pipe was installed in a well; this method has been used successfully ever since with only minor modifications.

Briefly, the procedure used in well construction by the rotary method is: (a) A hole is drilled to a depth of 40 or 50 feet and 14-inch steel casing is landed; (b) a pilot hole is drilled to a depth sufficient to penetrate a large part or the full thickness of the "A" sand; (c) the hole is reamed to a clay bed overlying the "A" sand, and 8-inch (inside diameter) steel casing is set; (d) the annular space between the 8-inch and 14-inch casings is filled with cement and the 14-inch casing is pulled; (e) the screen is made from 7¼-inch (outside diameter) cement-asbestos pipe by boring about 500 holes, each about ¾-inch in diameter in each 12-foot length of pipe, into which porcelain "buttons," having about $\frac{1}{16}$-inch slots, are cemented in recessed shoulders over each hole; (f) the screen is attached to threaded, blank cement-asbestos pipe of the same diameter and run into the hole until landed. Owing to the low tensile strength of the cement-asbestos pipe, the string of casing is suspended from the bottom by the drill pipe, and after landing, it is released from a reverse-thread coupling by turning the drill pipe. Rubber packers are placed at intervals as the pipe is installed, the lowermost packer being set at or near the bottom of the 8-inch steel casing to prevent upward leakage between the two strings of casing. Cement is used as a seal between the two casings only in the uppermost 1 to 2 feet of the well; and (g) the well is developed by flushing out the drilling mud and surging by use of a swab on the drill pipe.

Table 5 shows the number of wells drilled in the coastal plain since 1831. Of the 336 or more wells drilled since 1831, approximately 60 percent were still in use in 1956. Furthermore, of the 260 deep artesian wells drilled since 1913 nearly 80 percent were in use in 1956. For the period 1930–56, during which nearly all wells were constructed using cement-asbestos pipe, it is remarkable that of the 189 wells drilled, 180, or 95 percent, were being used in 1956. This is a high tribute to the methods and techniques of well construction used by the Pure Water Supply Scheme. By comparison, in the western part of the United States, wells are not expected to remain in use more than 20 years, and in several areas they are replaced in less than 10 years.

DISCHARGE FROM WELLS

During 1954-56 measurements were made by the pure Water Supply Scheme of the artesian flows of 200 wells that obtain their supply from the "A" sand unit of the White Sand series along the coast. The flows ranged from a few to nearly 400 Igpm. In table 6 the gross flows by coastal areas are compared to the initial gross flows of the wells when first drilled. Table 6 also shows a partial record of the estimated

TABLE 5.—*Wells drilled in the coastal artesian basin, 1831–1956*

[Compiled mostly from records of the Pure Water Supply Scheme]

Date	Wells drilled	Wells in use in 1956	Remarks
Shallow artesian wells			
1831–1912	76+	0?	Shallow artesian water in upper sand unit; largely brackish water; depth of wells 100 to 300 ft.
Deep artesian wells			
1913–19	30	3	Deeper artesian water in "A" sand unit; corrosion plugged or "ate out" casings and screens.
1920–24	0	--------	Investigating types of screens and casings to prevent loss of wells.
1925–29	41	21	Experimenting with and using brass and steel screens with relatively little success.
1930–34	18	17	Cement-asbestos screen and casing inside steel casing first used in 1931; the tabulation shows that the loss of wells has decreased substantially.
1935–39	26	25	
1940–44	31	27	
1945–49	43	42	
1950–54	56	55	
1955–56	15	14	
Total	336+	204	

TABLE 6.—*Discharge from 200 flowing artesian wells on the coastal plain*

[Compiled from records of the Pure Water Supply Scheme]

Area (table 1)	Wells	Gross flow (Igpm) on test		Estimated controlled flow, 1955	
		Initial	1945–56	(Igpm)	Acre ft per yr
Essequibo Coast	18	1, 400	1, 000	--------	--------
Wakenaam Island	7	500	100	--------	--------
Leguan Island	8	650	350	--------	--------
East Bank Essequibo	7	600	400	70	130
West Coast Demerara	17	2, 000	1, 400	--------	--------
West Bank Demerara	16	2, 000	1, 400	350	700
East Bank Demerara	18	2, 400	2, 100	500	950
Georgetown	10	2, 000	1, 700	850	1, 400
East Coast Demerara	36	7, 000	5, 600	--------	--------
West Coast Berbice	15	1, 500	1, 600	--------	--------
West Bank Berbice	4	500	350	--------	--------
East Bank Berbice	6	850	800	--------	--------
Canje-Berbice	7	700	700	--------	--------
Courantyne Coast	31	2, 200	1, 900	--------	--------
Total	200	24, 300	19, 400	--------	--------

discharge in 1955. To conserve the supply in most areas the wells are not permitted to flow at their full capacity.

The overall decline from the initial tested flows to the tested flows in 1954 and 1956 was about 5,000 Igpm, or a decrease of about 20 percent (table 6). The reasons for the decline may be one or more of the following: (a) Mutual interference between wells that caused a reduction in the flow of existing wells as additional wells were drilled; (b) decrease in artesian head in the aquifer after nearly 45 years of draft; (c) partial plugging of screens due to cementation or blockage by flakes of mica, which reportedly are abundant in the "A" sand; (d) choking of screens or accumulation of sand inside the well screens and consequent reduction in effective screen area; and (e) upward leakage around the casings to water-bearing zones of lower head, which probably is minor.

Mr. Burrowes of the Pure Water Supply Scheme reported that the flows of older wells have been increased substantially by thoroughly washing and surging in and above the screened parts of the wells. The increased flows that have exceeded the initial flows in some wells suggest that the wells were not fully developed when drilled. Thus, the decline in tested yields of the wells in large part may be due to causes c and d described above.

Table 6 also shows that in 1954–56 the total yield of the 200 wells was nearly 20,000 Igpm, or an average yield of about 100 Igpm per well. A sustained flow at this rate is equivalent to about 2[illegible] million Igpd or 37,000 acre-feet per year.

During 1954 the yields and drawdowns of 158 wells that derive their supply from the "A" sand were also tested to determine their specific capacities (yield in gallons per minute per foot of drawdown). To determine the drawdown, tests were made by measuring the static head above the discharge level after the wells were shut down for less than an hour. The discharge was measured by means of a weir or 10-gallon bucket—the latter for wells having a small flow. Table 7 shows the results of the tests; it shows also the yield factor, which is derived by dividing the specific capacity by the thickness of the aquifer to obtain gallons per minute per foot of drawdown per foot of thickness of the aquifer. This unit of measure is useful in comparing the yield data of one well with that of another when the thickness of the aquifer differs from one well or area to another.

Table 7 shows that for the several coastal areas the average specific capacities ranged from 5.6 to nearly 17 Igpm per foot of drawdown and yield factors ranged from 0.12 to 0.26 Igpm per foot. For individual tests the specific capacities ranged from 2 to 35 and yield factors ranged from 0.03 to 0.80. Because yield and head vary with the change in tide, it is necessary to measure both at the same stage of

TABLE 7.—*Average yield data from "A" sand for 158 artesian wells on the coastal plain*

[Compiled from records of the Pure Water Supply Scheme]

Area (table 1)	Wells	Flow (Igpm)	Drawdown (ft)	Specific capacity (Igpm per ft)	Aquifer thickness (ft)	Yield factor[1]
Essequibo Coast	16	60	5.9	10.2	44	0.23
Wakenaam and Leguan Islands	10	20	3.6	5.6	47	.12
West Coast Demerara	19	80	5.9	13.5	51	.26
West Bank Demerara	12	85	6.5	13.0	53	.25
East Bank Demerara	17	120	9.8	12.4	70	.18
Georgetown	9	155	9.3	16.7	63	.26
East Coast Demerara	32	145	13.7	10.6	79	.13
West Coast Berbice and West Bank Berbice	18	110	12.0	9.0	51	.18
East Bank Berbice, Canje-Berbice, Courantyne Coast	25	80	6.7	12.0	61	.20
Weighted average	------	100	8.8	11.3	60	.19

[1] Yield factor: gallons per minute per foot of drawdown per foot of aquifer thickness.

the tide to obtain an accurate value of specific capacity. For example, in 1954 at the Hubu well, East Bank Essequibo, the flow at low tide was 16 Igpm and the head was 0.8 foot above the measuring point, and at high tide the flow was 50 Igpm, and the head was 2.7 feet above the measuring point. In this case, either set of data will provide about the same value of specific capacity. An examination of the tests made by the Pure Water Supply Scheme shows that care has been taken in the collection of the flow and head data.

ARTESIAN HEAD IN COASTAL WELLS

The apparent head decline in the deep artesian wells has raised doubts concerning the adequacy of the ground-water supply. The term "apparent head decline" is used in contrast to the term "true head decline," which the available records do not show. In any event the true head decline would be less than the apparent head decline, which from 1926 to 1956 amounted to a maximum of 8 feet in the West Coast Demerara area. To evaluate the true head decline, the methods used in making the head readings, the physical forces in operation in the aquifer at the time the measurements were made, and the possible extraneous influences all must be considered. These factors are discussed in the following sections.

APPARENT HEAD DECLINE IN THE "A" SAND

In 1954 the Pure Water Supply Scheme made measurements of head in nearly all the existing wells, and in 1956 measurements were made again in wells in the coastal areas southeast of the Demerara

River. Except for a few miscellaneous readings, these were the first measurements made since the wells were completed. The head at each well was measured in feet above the land surface. Unfortunately, the altitudes of the wells and of the land-surface datum[2] are not known. However, as mentioned previously, the altitude of the land surface along the coast reportedly ranges from less than 1 foot to about 3 feet above mean sea level. Thus, although this range is small, the analysis of the records described below may be subject to an error of as much as 3 feet.

To study the magnitude of the apparent decline, considerable time was spent in collecting old records and plotting hydrographs of all the wells. The records of all the wells in each of the 14 coastal areas (table 1) were prepared as a group or composite hydrograph. This procedure provided a means of eliminating from consideration any well that showed an unusual decline or departed radically from the general trend of the other records in that particular area. Mr. Burrowes indicated that most of the wells showing unusually rapid declines in head probably had developed leaks through or outside the casing.

Table 8 shows the initial head, the heads in 1954 and 1956, and the apparent average head decline by areas for the period of record in the "A" sand in the coastal area as determined from the records for 186 artesian wells. Very few records are available for the deep wells drilled between 1913 and 1919, and those are contradictory. For example, in the Georgetown area the initial head in that period was reported to be 16 feet above the land surface in some records and 20 feet above in others. Accordingly, these data have not been used. Similarly, initial heads in a few wells in the West Coast Berbice and West Bank Berbice areas reportedly were 27 to 29 feet above the land surface. These records may be in error and have been omitted from consideration at this time.

The apparent head decline through 1954 for the 14 areas averaged 3.5 feet (table 8). The incomplete records for 1956 suggest that the decline through 1956 may have been about 4 feet. Although the head declines appear small, they are critical to the supply because it was decided to depend upon artesian head to obtain the water. It has been decided not to pump the coastal wells, not only because the equipment and operation would be costly but also because of the increased hazard of sea-water intrusion.

Theoretically the decline in head is approximately proportional to the decline in flow or discharge. For example, a 20-percent decline in head results in about a 20-percent decline in flow. The apparent de-

[2] The land-surface datum is a precise datum approximating the land surface at the well at the time the datum was established and tied in by leveling to some permanent reference point on the well or nearby. The land surface at the well may change, but the land surface datum remains the same.

TABLE 8.—*Artesian head and apparent average head decline in 186 coastal wells, 1926–56*

[Compiled from records of the Pure Water Supply Scheme and from reports]

Area (table 1)	Wells	Average depth zone (table 4)	Average head in feet above land surface [1]				Apparent decline through 1954 (feet)
			Initial		1954	1956	
			Year	Head			
Essequibo Coast	16	260–310	1936	9.5	7.0	--------	2.5
Wakenaam Island	7	255–300	1936	6.5	5.0	--------	1.5
Leguan Island	8	285–340	1928	7.0	5.0	--------	2.0
East Bank Essequibo	5	360–400	1926	11.0	7.5	--------	3.5
West Coast Demerara	16	510–570	1927	15.5	7.5	--------	8.0
West Bank Demerara	15	500–550	1931	13.5	9.0	--------	4.5
East Bank Demerara	18	500–570	1929	15.5	10.0	9.5	5.5
Georgetown	10	640–720	1926	16.5	11.0	10.5	5.5
East Coast Demerara	35	740–820	1927	18.5	15.0	14.5	3.5
West Coast Berbice	13	940–1,000	1926	18.5	15.0	--------	3.5
West Bank Berbice	4	870–910	1928	15.5	11.0	10.5	4.5
East Bank Berbice	6	890–960	1928	13.0	12.0	11.0	1.0
Canje-Berbice	7	850–940	1938	12.5	9.5	9.0	3.5
Courantyne Coast	26	930–990	1928	9.0	7.5	7.0	1.5
Average	--------	------------	--------	13.0	9.5	--------	3.5

[1] For each year and in each area the head shown is the average for all wells whose records conform to the general water-level (head) trend. Individual head readings range only from 1 to 3 feet above and below the average shown.

cline in head through 1954 ranged from a minimum of about 10 percent in the East Bank Berbic area to about 50 percent in the West Coast Demerara area and averaged about 25 percent for all areas, which agrees closely with the decrease in flow of about 20 percent (p. 20). However, the measurements of head were not made under controlled conditions, for the following two principal reasons:

First, the mutual interference between the wells was not considered. The head in each well was measured while all other wells were allowed to flow at their regulated rates. This situation is analogous to an attempt to measure the maximum head in a city water system when many of the taps are turned on. The ideal arrangement would be to stop the flow of all the coastal artesian wells for at least a week or two to allow the head to recover substantially, then make head readings at the wells. However, for obvious reasons this procedure would not be practicable. Therefore, it is suggested that to determine the amount of decline in each selected well, future measurements of head be made by stopping the flow of wells in a radius as large as possible (at least 5 miles) and for as long a time as practicable (at least 3 days). The tidal fluctuations in the well should be recorded during this interval. If the head is still recovering at the end of 3 days, the measurements of head versus time should plot as a nearly straight line on semilogarithmic paper, and the line can be extrapolated to determine what the approximate head would be a month later. The results would provide a reasonably accurate estimate of the "static" artesian head and, when compared with the initial head, a relatively good measure of the true head decline.

Second, it is not known to what extent the artesian heads recorded at the wells are affected or reduced by mechanical defects in the well, such as leakage through the casing joints, past the packers between casings, through rusted sections in the outside steel casing, or upward outside the casing to sand that is under lower head. A deep-well current meter could be used to detect upward leakage inside the casing, but no method is known to determine upward leakage outside the casing.

HEAD IN THE UPPER SAND

Although none of the existing artesian wells derive water from the upper sand unit of the White Sand series, the artesian head was tested during the construction of several deep wells. As indicated above, the head in the upper sand is lower than that in the "A" sand and hence affords a potential zone for the disposition of water that might leak upward in defective deep wells.

In general the head in the upper sand ranges from 3 to 5 feet above the land surface. Along the Essequibo Coast and on the Wakenaam and Leguan Islands, where the "A" sand is at shallow depth (table 8), the head in the "A" sand is only slightly higher than that in the upper sand. In the East Coast Demerara and West Coast Berbice areas, where the "A" sand is deep and where the initial heads averaged more than 18 feet, the sand beds in the overlying intermediate clay unit showed an increasing head from about 5 feet in the upper part to as much as 12 to 14 feet in the lower part. Locally in the vicinity of the Courantyne River the intermediate clay unit and the lower clay unit are more sandy and the distinction between zones is less apparent; the head ranged between 3 and 6 feet to a depth of 1,200 feet and from 10 to 17 feet between 1,300 and 1,500 feet.

As shown in table 5, at least 76 wells drilled between 1831 and 1912 obtained their supply from the upper sand and were completed as flowing wells. Unfortunately, none of the records were found during this study, and no analysis could be made of any head changes that may have occurred in the upper sand.

SOURCE OF THE ARTESIAN HEAD AND SUPPLY

The source of the artesian head and the supply to wells is the recharge area of the White Sand series, which is exposed over an area of about 5,000 square miles. The recharge is supplied by infiltration of rain in an area where rainfall averages nearly 100 inches per year, and possibly in places by seepage loss from the major rivers, which have large annual discharges (table 12). Because of the large recharge potential, the relatively small annual discharge from the coastal artesian wells probably has caused little, if any, change in ground-water levels in the recharge area. If this is true, the heads in the coastal wells would return to or closely approach their initial levels, provided all flows were stopped for a period of several years.

Prior to the construction of the first artesian wells, the head in the shallow and deep aquifers along the coast was controlled by several physical conditions. The artesian head in the sand forming the shallow aquifer reaches its highest altitude in the outcrop area south of the contact between the White Sand series and the coastal sediments (pl. 1) which confine the water in the upper sand unit. Along the contact the head may be about 25 feet above sea level. Coastward, the head becomes progressively lower as a result of friction or transmission loss, which is a function of the transmissibility of the aquifer, upward leakage through the overlying Coropina formation and Demerara clay, and other means of natural discharge. Presumably the bulk of the natural discharge is submarine, through the surficial clays or possibly beyond them at a submarine outcrop of the upper sand. The relation of the head at the coast to natural discharge is discussed in the section on quality of water.

The heads in the "A" sand and deeper aquifers probably also reach their highest altitudes in the southern part of the outcrop area, and head loss occurs coastward for the same general reasons just described. Because the White Sand series dips northward and because the head in the deep aquifers at the coast is higher than that in the shallow aquifer, it is reasonable to assume that, except possibly west of the Essequibo River, the altitude of the water level in the recharge areas of the "A" sand and deeper sands is considerably higher than 25 feet above mean sea level.

The drilling of the first artesian wells upset the natural dynamic balance in the aquifers that had been in operation for several thousand years. The initial head measurements, although varying greatly along the 150-mile coast, represented the levels under natural conditions as established by the regimen of recharge and discharge. The drilling of these and subsequent wells upset the natural balance by providing an artificial form of discharge. The head in the aquifers adjusted to this additional discharge by declining, first in the vicinity of the wells, then progressively farther away in all directions to create the hydraulic gradient necessary to supply a quantity of water equal to the discharge of the wells. The decline at a well continues until the cone of depression intersects a source of recharge, such as the landward outcrop area or, unfortunately in coastal areas, the ocean, or both. Owing to the lack of observation wells south of the coastal strip, no data are available to determine whether the cones of depression have intersected the recharge area. Much more critical to the supply is the effect of the decline in head at the wells on the status of sea-water intrusion in the submarine parts of the aquifers, which is also discussed in the section on quality of water.

As more and more wells were drilled into the "A" sand to obtain a supply of flowing water, the cones of depression extending out from each intersected and caused additional head decline at each well, or mutual interference among wells, and a corresponding decrease in flow. In 1956 there were about 200 actively flowing wells, the distance between them averaging less than 1 mile. Because the cone of depression at each well will extend outward many miles to intercept a source of recharge, it is obvious that the head at any one well is a measure of the composite interference effect caused by the discharge from and the drawdown in all wells within a radius of several tens of miles, though the bulk of the interference is caused by the nearest wells. Thus, the measurements of head made in 1954 and 1956, although accurately depicting the head in the aquifer while the other wells were flowing, cannot be compared with the initial head in the first well that was drilled in the area, when no other wells were flowing, to obtain an accurate measure of the true head decline. Similarly, the measurements of flow in 1954 and 1956 cannot be compared with the initial flows for the same reason.

COEFFICIENTS OF TRANSMISSIBILITY, FIELD PERMEABILITY, AND STORAGE

The hydraulic properties of an aquifer are expressed by the coefficients of transmissibility (T), permeability (P), and storage (S), which have been described by Wenzel (1942), Brown (1953), and others. Several methods have been developed by Thiem (1906), Theis (1935), Jacob (1940; 1950), Ferris (1952), and others for determining the coefficients by making controlled discharge tests on wells or using other hydrologic data. Because freely flowing wells, such as those in British Guiana, have the same effect on an aquifer as pumped wells, tests can be made and the necessary information obtained using the flowing wells and nearby observation wells. Nevertheless, the tests are still termed pumping tests, or aquifer tests. Four methods were used to estimate the coefficients of transmissibility and permeability, and two of these provided estimates of the coefficient of storage.[3] Two controlled tests were made in the Georgetown area between Mar. 16 and Apr. 18, 1957.

An approximation of the transmissibility sometimes can be obtained by use of the specific capacities (table 7) and the Thiem formula, which can be expressed:

[3] All coefficients are presented in U.S. units. If conversion to Imperial units is desired, multiply U.S. units by 0.83.

$$T = 527.7 \frac{Q}{s_w} \log_{10} \frac{r_e}{r_w} \tag{1}$$

where Q is the discharge of the well in gpm; s_w is the drawdown in the pumped well, in feet (Q divided by s_w is the specific capacity); r_e is the effective radius of the cone of depression, in feet; and r_w is the effective radius of the well, in feet.

This approximation is introduced because so many specific-capacity tests are available. Also, the results can be compared with those obtained from the field tests to ascertain the overall efficiencies of the wells. Of the 158 tests (table 7), the highest 50 percent have been selected, because the lowest 50 percent may contain many that would reflect unusually high entrance losses. The highest 50 percent average about 20 USgpm per foot of drawdown. The effective well radius is not known but must be taken as the actual radius of the well, or about 0.4 foot, and, because the wells have been flowing for many years, the effective radius of the cone of depression probably is at least 25,000 feet. Thus, substituting in equation (1):

$$T = 527.7 \times 20 \times \log_{10} \frac{25{,}000}{0.4} = \text{about } 50{,}000 \text{ gpd per ft}$$

The field coefficient of permeability (P_f) is equal to the transmissibility (T) divided by the thickness of the aquifer (m), in feet, as follows:

$$P_f = \frac{T}{m} \tag{2}$$

Thus, substituting in equation (2) the T of 50,000 gpd per ft and the average thickness of the "A" sand of 60 feet (table 7):

$$P_f = \frac{50{,}000}{60} = \text{about } 800 \text{ gpd per sq ft}$$

The second method used is the Theis nonequilibrium formula (Theis, 1935), known as the type-curve solution (Brown, 1953; Wenzel, 1942). Coefficients of transmissibility and storage are obtained by plotting values of drawdown (s) in the observation well versus values of the radius (distance between wells in feet) squared divided by the time in days $\left(\frac{r^2}{t}\right)$ on log-log paper and superposing a "type" curve to obtain a "match point" and values of u, $W(u)$, s, and $\frac{r^2}{t}$ for use in the following equations:

$$T = \frac{114.6 Q \times W(u)}{s} \tag{3}$$

$$S=\frac{Tu}{1.87\,\frac{r^2}{t}} \tag{4}$$

Two controlled pumping tests were made at the wells at and near the Georgetown Water Works. An automatic water-level recorder was operated on Shelter Belt well 2 during one test and on the Campbelville well during the other. Shelter Belt well 1, which flowed 370 to 380 USgpm, was the discharging well for both tests. Data obtained from the tests are substituted in equations (3) and (4):

Shelter Belt well 2

$$T=\frac{114.6\times375\times1.0}{0.225}=190{,}000 \text{ gpd per ft}$$

$$S=\frac{190{,}000\times0.1}{1.87\times(6.9\times10^7)}=0.00015$$

Campbelville well

$$T=\frac{114.6\times380\times1.0}{0.33}=130{,}000 \text{ gpd per ft}$$

$$S=\frac{130{,}000\times0.1}{1.87\times(2.75\times10^7)}=0.00025$$

As a check on the type-curve solution, the data from these tests were used also in the modified nonequilibrium method developed by Cooper and Jacob (1946). Coefficients of transmissibility and storage were obtained by plotting values of time (t) in minutes versus drawdown (s) in feet on semilogarithmic paper; a straight line was drawn through the points having large values of time to obtain t_o at the intercept on the zero-drawdown axis and Δs for one log cycle for use in the following equations:

$$T=\frac{264Q}{\Delta s} \tag{5}$$

$$S=\frac{Tt_o}{4{,}790r^2} \tag{6}$$

Substituting the field data obtained from the two tests in equations (5) and (6):

Shelter Belt well 2

$$T=\frac{264\times375}{0.48}=200{,}000 \text{ gpd per ft}$$

$$S=\frac{200{,}000\times0.47}{4{,}790\times(1.59\times10^5)}=0.00013$$

Campbelville well

$$T=\frac{264\times 380}{0.66}=150{,}000 \text{ gpd per ft}$$

$$S=\frac{150{,}000\times 51.0}{4{,}790\times(8.25\times 10^6)}=0.0002$$

The results check, as is to be expected.

The third and fourth methods utilize the cyclic methods of determining transmissibility (Ferris, 1952); the storage coefficient must be known. The effects of tidal loading along the coast caused fluctuations of artesian head in the three selected observation wells—Subryanville, Campbelville, and Shelter Belt well 2—at each of which an automatic water-level recorder was operated for at least a week. The information collected from these records can be used in the time-lag and range-ratio equations to determine transmissibility, respectively, as follows:

$$\textit{Time lag } T=\frac{0.60x^2t_oS}{t_l^2} \tag{7}$$

and

$$\textit{Range ratio } T=\frac{4.4(\Delta x)^2S}{t_o} \tag{8}$$

in which x is the distance in feet from the well to the shoreline at mean sea level; Δx is the distance in feet measured over one log cycle on the data plot; t_o is the time in days for one tidal cycle (peak to peak or trough to trough); and t_l is the time lag in days between tide time and the time the tidal effect reaches the well. The storage coefficient used is the average obtained from equations (4) and (6), or about 0.0002. Substituting the field data obtained from the three wells in equation (7):

Subryanville well

$$T=\frac{0.60\times(3{,}000)^2\times 0.52\times 0.0002}{(0.052)^2}=200{,}000 \text{ gpd per ft}$$

Campbelville well

$$T=\frac{0.60\times(6{,}000)^2\times 0.52\times 0.0002}{(0.10)^2}=220{,}000 \text{ gpd per ft}$$

Shelter Belt well 2

$$T=\frac{0.60\times(8{,}300)^2\times 0.52\times 0.0002}{(0.125)^2}=270{,}000 \text{ gpd per ft}$$

Equation (8) in part requires a graphical solution which involves a plot on semilogarithmic paper of the range ratio, or tidal efficiency, versus the distance of the well from the shoreline at mean sea level. The point plots for the three wells fell on a straight line from which a Δx of 8,600 feet was obtained for one log cycle. It is of interest, also, that the point where the straight line intersects the range ratio of unity, which is supposed to be at the distance to the submarine outcrop of the aquifer, is about 4,000 feet seaward from the shore at mean sea level. This distance seems too close to shore to be valid (see p. 10). Nevertheless, the data are substituted in equation (8):

$$T=\frac{4.4\times(8{,}600)^2\times 0.0002}{0.52}=125{,}000 \text{ gpd per ft}$$

Table 9 summarizes the results obtained from the several tests and methods and shows wide ranges in the coefficients. For the field tests that were made in Georgetown the results suggest a transmissibility of about 180,000 gpd per foot, a field permeability of about 1,800 gpd per square foot, and a storage coefficient of about 0.0002.

TABLE 9.—*Estimated coefficients of transmissibility, field permeability, and storage for the "A" sand*

Method, well	Transmissibility (USgpd per ft)	Field permeability (USgpd per sq ft)	Storage
Coastal area (average aquifer thickness 60 feet, table 7)			
Thiem (80 wells)[1]	50, 000	800	----------
Georgetown area (aquifer thickness about 100 feet in Shelter Belt well 1)			
Thiem:[1]			
Shelter Belt well 1	100, 000	1, 000	----------
Theis nonequilibrium:			
Shelter Belt well 2	190, 000	1, 900	0. 00015
Campbelville well	130, 000	1, 300	. 00025
Modified nonequilibrium:			
Shelter Belt well 2	200, 000	2, 000	. 00013
Campbelville well	150, 000	1, 500	. 0002
Cyclic, time lag:			
Shelter Belt well 2	200, 000	2, 000	----------
Campbelville well	220, 000	2, 200	----------
Subryanville well	270, 000	2, 700	----------
Cyclic, range ratio:			*Range ratio*
Shelter Belt well 2	125, 000	1, 200	0. 035
Campbelville well			. 064
Subryanville well			. 144

[1] Approximated from specific capacities of wells: coastal area about 20 USgpm per ft; Shelter Belt well 1 about 40 USgpm per ft.

The coefficients obtained from the brief tests on three of the wells in the Georgetown area obviously cannot be applied to the entire 150-mile coast. One set of quantitative data in a local area does not satisfy the demand for a quantitative study of an aquifer. It is merely a segment of knowledge, which should be supported by additional tests. Often the initially calculated results may require revision on the basis of discoveries resulting from additional testing. Once the hydraulic characteristics of the aquifer have been established, suitable equations are available for use in predicting the rate of water-level or head decline in an aquifer having a given discharge, establishing the proper spacing of wells, designing and constructing wells for optimum yield, and estimating ground-water underflow and recharge to the aquifer.

The transmissibilities and field permeabilities obtained by the field tests, although having a wide range, are considerably larger than those obtained by the approximation method using specific capacity and the Thiem formula. It is possible that head loss in the 6-inch inside-diameter cement-asbestos casing, which extends from about 300 to 1,500 feet below the land surface (table 4), may be as much as 1 foot per 100 feet of 6-inch casing for wells having a discharge of 300 gpm. In addition, other head losses occur in the aquifer adjacent to the well and in the screen, so that the drawdowns used to compute the specific capacities given in table 7 are greater than the theoretical drawdown, as postulated in the Thiem equation, necessary to move the water through the aquifer to the well. Thus, the transmissibilities as computed by the Thiem equation probably are considerably lower than the true transmissibility.

Owing to the relatively high temperature of the ground water, which ranges from about 85° to 100°F in the "A" sand, the field coefficient of permeability would have to be corrected to a water temperature of 60°F, the temperature at which the "laboratory" coefficient is defined, if it is to be compared with those in other countries. The factor for converting the coefficients obtained in the Georgetown tests (the water discharged from Shelter Belt well 1 was at 93°F) is about 0.66. Thus, the laboratory coefficients are about two-thirds of the field coefficients. However, for application of the coefficients to quantitative work in the coastal basin of British Guiana, the field value should be used.

GENERAL QUALITY OF WATER

More than 400 chemical analyses of well water were published by Harrison (1913, 1914a, 1914b) and are in the files of the Pure Water Supply Scheme. These records have been tabulated and studied, and the pertinent features of ground-water quality are summarized herein.

This summary includes the general character in the shallow and deep artesian aquifers, the status of sea-water intrusion, and comments on the quality in the coastal segments of the major rivers.

SHALLOW ARTESIAN WATER

The results of 56 complete analyses of water from 43 shallow artesian wells for years before 1913 are presented in a report by Harrison (1913, p. 6). Of these wells, 30 contained chloride in excess of 250 ppm (parts per million), which the U.S. Public Health Service (1946) recommends as the upper limit for drinking water used on interstate carriers. The chloride ranged from 6 to 1,770 ppm, sodium from 24 to 1,330 ppm, the dissolved solids from 190 to 3,400 ppm, and iron (ferrous) from 0.9 to 100 ppm. Two samples analyzed for aluminum contained 20 and 55 ppm. Most of the waters are high in chloride and are classified as the sodium chloride type. In general, the shallow artesian aquifer contains water that is not potable. The poor quality of water was one of the principal reasons that the test for a deep artesian supply was undertaken in 1913.

Table 10 was taken from a report by Harrison (1914b, p. 11), which describes the character of the water penetrated in the Bonded Warehouse well. The methods of analysis are not known. Significant changes in chemical quality of water occur with depth and generally are representative of the coastal conditions. The well penetrated sand lenses in the Demerara clay above 124 feet, the upper sand unit between 185 and 303 feet, sand lenses in the intermediate clay unit between 354 and 612(?) feet, and the "A" sand below 640 feet. The analyses show a moderately mineralized sodium chloride water in the two thickest sands above a depth of 303 feet, which is near the base of the upper sand unit; a less-concentrated water of intermediate type between 354 and 504 feet in the intermediate clay unit; and a rather dilute sodium bicarbonate water below 601 feet, largely in the "A" sand unit. Thus, the quality of water in this and in most other coastal wells improves with depth, the water of best quality being contained in the "A" sand.

The increase in water temperature with depth in the well indicates a geothermal gradient of about 1° F per 70 feet of depth (table 10). Water from an average depth of about 725 feet in Shelter Belt well 1 had a temperature of 93° F on Apr. 1, 1957; this fact suggests a geothermal gradient of 1° F per 65 feet of depth. Similarly, water derived from an average depth of 1,200 feet in Whim well 3 in the Courantyne Coast area had a temperature of 100° F on Mar. 5, 1957; a geothermal gradient of 1° F per 70 feet of depth is suggested. Thus, those few but consistent data indicate that the gradient is relatively uniform along the coast.

TABLE 10.—*Quality of water in the Bonded Warehouse well, Georgetown*

[Analyses in parts per million. After Harrison (1914b)]

Depth (feet)	Temp. (° F)	Dissolved solids (calculated)	Silica (SiO_2)	Iron, Ferrous (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)[1]	Sulfate (SO_4)	Chloride (Cl)	Strata
87	83	426	70	2.1	5.9	24	83	11	40	25	185	Sandy clay.
115-124	83	418	40	2.6	nil	43	74	12	28	46	186	Sand.
185-237	83	1,790	60	1.9	24	94	496	39	98	86	942	Do.
237-244	84	481	15	.4	7.7	14	162	7.6	67	25	215	Clay and sand.
274-303	84	1,360	26	1.4	36	64	380	17	65	104	699	Sand.
354-362	84	284	7.9	.9	10	12	73	9.1	33	24	131	Do.
411	84	191	40	.3	9.7	8.6	49	9.1	78	4.3	31	Do.
434	85	117	28	4.7	6.4	5.3	23	6.4	44	1.5	20	Do.
492	86	169	23	9.0	6.7	22	21	6.6	69	3.4	43	Sandy silt.
504	87	134	23	.5	7.7	19	18	9.8	75	1.0	17	Do.
601-612	88	156	21	8.8	6.0	24	23	7.3	105	2.6	11	Sand.
640-668	90	65	9.5	4.7	3.2	4.3	15	3.7	30	Nil	9.0	"A" sand.

[1] Carbonate, if any, and bicarbonate converted to carbonate.

DEEP ARTESIAN WATER

The results of more than 300 analyses for the 200 existing deep artesian wells that are screened in the "A" sand unit are in the files of the Pure Water Supply Scheme. Unfortunately, the analyses are partial, in that only sodium, chloride, iron (ferrous), acidity as free carbon dioxide, dissolved solids, ammonia, and pH were determined in most cases. The analyses have been collected since 1926. In 1954 nearly all wells were sampled to determine any change in the chloride content. In general, no change had occurred since the wells were drilled.

Table 11 shows the range in concentration and average for the determined constituents, dissolved solids, and pH in the "A" sand unit as compiled from most of the analyses made since 1926. In general the quality of water improved from the Essequibo Coast area southeastward to the Canje-Berbice area, then is progressively poorer toward the Courantyne River, where the intermediate clay becomes sandier and poor-quality water extends to greater depth, possibly into the upper part of the "A" sand unit. The water is extremely dilute between the West Coast Demerara and Canje-Berbice areas. In the absense of analyses for the principal cations and anions the type of water is unknown, and whether it differs from one part of the area to another could not be determined. A few analyses for fluoride were made; all show less than 0.6 ppm.

The low pH of the water and the large amount of carbon dioxide were designated by Harrison and Buck (1919) as the principal reason for the rapid corrosion of the steel casings and mixed-metal casing and screens. The high concentration of iron makes the water unsuitable

TABLE 11.—*Summary of 237 chemical analyses for the deep artesian wells, 1926–56*

[Compiled from records of the Pure Water Supply Scheme. Analyses in parts per million]

Area (table 1)	Analyses	pH		Dissolved solids		Chloride		Iron (ferrous)		Acidity as free CO_2	
		Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
Essequibo Coast	24	5.2–5.8	6.2	92–375	250	39–123	75	0.5–17	7.2	22–73	48
Wakenaam Island	8	6.3–6.9	6.7	214–337	280	42–99	60	1.8–19	11.7	22–79	40
Leguan Island	9	6.3–6.7	6.5	135–1,127	275	19–350	64	.4–20	2.9	18–79	35
East Bank Essequibo	6	6.1–6.5	6.3	130–300	190	21–56	36	2.8–29	9.2	18–77	50
West Coast Demerara	20	6.1–6.5	6.3	102–173	134	7–30	17	.6–4.0	2.0	22–42	34
West Bank Demerara	18	5.9–6.4	6.1	63–138	90	3–18	10	.5–5.4	3.1	10–53	34
East Bank Demerara	13	5.6–6.9	6.1	44–132	80	7–18	11	1.6–8.3	3.4	22–59	31
Georgetown	17	6.1–6.5	6.3	80–174	110	7–14	11	2.0–16	5.1	15–40	32
East Coast Dermerara	46	5.0–6.7	6.1	56–164	95	3–32	11	.2–10	3.9	18–62	34
West Coast Berbice	19	5.7–7.0	6.1	57–153	102	4–28	12	2.0–10	4.8	22–68	44
West Bank Berbice	4	5.9–6.3	6.1	76–150	110	7–10	8	4.0–10	7.0	42–51	46
East Bank Berbice	10	5.3–6.1	5.8	62–130	90	7–25	12	1.2–8.4	5.3	29–68	48
Canje-Berbice	5	5.8–6.1	5.9	72–102	90	5–11	9	2.8–5.2	4.1	29–53	44
Courantyne Coast	36	5.6–7.0	6.3	80–444	190	2–250	45	.5–8.0	3.7	15–62	35

for many uses. In observing the discharge of several wells, the author noted a rapid precipitation of iron in ditches, undoubtedly caused by oxidation and release of carbon dioxide from the water. For domestic use the flow from a well is directed over a rough concrete flume to reduce the carbon dioxide and iron content; it then enters a concrete tank to pass through a sand filter and crushed limestone, and discharges relatively free of carbon dioxide, greatly reduced in iron content, and reportedly having a pH of nearly 7.0.

As for the deeper aquifer or aquifers underlying the "A" sand in the Georetown area and near New Amsterdam, which are described in the section on the White Sand series, the electric logs show only that the water is fresh. Inasmuch as the only known undesirable constituent in the water is the high iron content, testing of the deeper aquifer would be warranted not only to determine its yield but also to analyze the iron content, in addition to the principal constituents. The iron content in the upper sand averages more than 25 ppm and in the "A" sand averages about 5 ppm; this decrease may continue progressively with depth.

STATUS OF SEA-WATER INTRUSION

Sea-water intrusion into the aquifers must be considered as a potential threat to the quality of water and consequently to the adequacy of the supply. A common fallacy is that no threat is involved where the supply is derived wholly from the flow of wells rather than from pumped wells. The principal advantage of a supply derived from a flowing well, other than economic, is that the head can be reduced only to the land surface, and the maximum drawdown and rate of ground-water movement toward the well thereby limited, whereas actually in a pumped well the head can be drawn down below the land surface to a depth governed by the physical and economic limits of operation; the well discharge and rate of movement will be increased in proportion to the drawdown. A definite relation exists between drawdown in either flowing or pumped wells and the hydraulics of sea-water intrusion.

Some unknown distance off the coast of British Guiana the upper sand and the "A" sand aquifers probably are in hydraulic continuity with the waters of the Atlantic Ocean. If the head in the aquifers is sufficient to displace the denser waters of the ocean, then the aquifers will discharge to the sea; if not, then saline waters will enter the aquifer and move coastward to a point where the fresh-water head in the aquifer is sufficient to maintain the balance between the two fluids of different density.

To determine where the contact, or interface, between the fresh and saline waters might be in the aquifers along the coast, it is necessary to apply the so-called Ghyben-Herzberg theory, as used by Brown (1925). Fundamentally the principle involved deals with the density differential between the two fluids, which in most areas is about 1.025 (sea water) to 1.000 (fresh water). In proportion to this slightly greater density of sea water, the interface between the two fluids will be depressed about 40 feet below sea level for each foot of fresh-water head above sea level.

However, along the coast of British Guiana the problem is to determine the density of the water in the ocean and in the seaward parts of the aquifers. For example, in the files of the British Guiana Geological Survey, notes prepared in 1916 by J. B. Harrison show the relative proportions of the offshore sea waters as follows:

Site	*Sea water (percent)*	*Fresh water (percent)*
Harbour mouth, Georgetown	13. 6	86. 4
Offshore (miles):		
One fourth	31. 7	68. 3
4	72. 2	27. 8
11	82. 2	17. 8
18–32	86. 8	13. 2
39	89. 9	10. 1
46–80	92. 7	7. 3

Notes prepared by Harrison in 1917 state that the dissolved solids 2 miles offshore were 6,480 ppm and 11 miles offshore were 20,100 ppm, compared to a mean for tropical sea water of 35,200 ppm. For all the above data the depth of the sampling is unknown; surface samples probably would be more dilute than samples collected at or near the ocean floor. The source of the fresh, mud-laden coastal waters has been attributed to the discharge of the Amazon River and other major streams to the east that is carried west-northwestward along the coast by the North Equatorial Current. Because the density of the sea water in the aquifer offshore is not known, the Ghyben-Herzberg theory cannot be applied, but it can be stated that any dilution would make the density differential smaller; that is, for each foot of fresh-water head above sea level the interface would be depressed to some depth greater than 40 feet below sea level—the lower the density of the dilute sea water the greater the depth to the interface. Nevertheless, the measurements of initial head, the head in 1954, and the quality of water in the "A" sand unit and the head and quality of water in the upper sand unit provide limited information on the status of sea-water intrusion.

In the upper sand unit the shallow artesian wells tapped sodium chloride water which undoubtedly is modified or dilute sea water. Its presence apparently is not the result of intrusion caused by draft on ground water, because the first wells drilled tapped the water already in the aquifer. The brackish to saline water in the upper sand may be incompletely flushed sea water that has been held in the deposits since the last time the sea was high enough to flood the sand, or more likely it may be salt water that is in hydraulic balance with the fresh-water system in the sand.

The head in the aquifer has been only 3 to 5 feet above land surface, which may be 1 to 3 feet above mean sea level; that is, the head may range roughly from 4 to 8 feet above mean sea level. Under conditions where undiluted sea water was in the aquifer, the fresh-water head would be sufficient to depress the fresh water-salt water interface to a depth of only 160 to 320 feet, using the ratio of 1 to 40 already described. Obviously, in most of the coastal plain the head is not sufficient to expel the sea water from the coastal part of the upper sand. Whether the sea water along the coast was as dilute when the sand was last flooded as it now is, of course, not known.

In the "A" sand unit the deep artesian wells have been supplying water of good quality for more than 40 years, and there has been no evidence of sea-water intrusion or deterioration of the quality through 1956 (table 11). As of 1956, no known deep wells had a chloride content in excess of 250 ppm.

Table 8 shows that the average initial head in the coastal wells ranged from 6.5 to 18.5 feet above land surface, or about 8 to 21 feet above mean sea level, assuming the land surface to be about 1 to 3 feet above mean sea level. If the water in the seaward part of the aquifer were undiluted sea water, then the theoretical depth to the fresh water-salt water interface could be approximated by multiplying the initial head above mean sea level (the head above land surface from table 8 plus not more than about 3 feet) by 40. It can be computed that the depth to the theoretical position of the interface would range from about 200 feet deeper to about 500 feet shallower than the average depth to the base of the sand as shown in table 8. For 1954 and 1956 the head data indicate that the theoretical position of the interface would be within the average depth zone in which the well screens are set in 11 of the 14 coastal areas. When the wells are flowing, of course, the head is only a few feet above mean sea level, and the interface would tend to be even higher.

However, no evidence of salt-water intrusion was detected in the review of the available analyses. That no intrusion into the wells has occurred may be due to one or more of the following: (a) The sea water in the offshore part of the aquifer is dilute, the effect of which already has been explained; (f) the initial head measured in the wells may have been less than the true head because of leakage around the well bores, but this is not likely because the effect would have had to occur about equally in all the wells; (c) there is little or no hydraulic continuity between the aquifer and the ocean, perhaps because of lateral facies change or faulting, and hence little or no ground water could move toward the wells from the seaward part of the aquifer; and (d) warping or folding of the deposits beneath the Continental Shelf, which could have raised the aquifer to shallow depth, in conjunction with the past and present (1956) head would have prevented the landward movement of salt water. However, the known minor warping of the White Sand series seems to preclude the latter hypothesis.

If there is hydraulic continuity or interconnection between the aquifer and the ocean and if saline water does occur in the aquifer some distance offshore, the discharge from the flowing wells along the coast may eventually result in contamination of the wells, if the recharge from the landward side is not adequate for water to move around or between the wells and maintain a ground-water divide between the wells and the sea. If there is no such divide but the saline water is dilute, the quality of the water would tend to deteriorate slowly. There is no cause for general alarm about the imminence of sea-water intrusion, because apparently no intrusion has occurred along the 150-mile coastal strip even though most of the existing wells have been in operation since 1930. However, studies are needed to evaluate the perennial supply of potable water and to search for an alternative source of ground-water or surface-water supply, or both.

SALT WATER IN COASTAL STREAMS

During the dry seasons of the year (table 3), which in some years are long enough to constitute droughts, the flows of the rivers reach a minimum discharge. At those times the ocean water, which is brackish, makes its farthest inland advance, and its quality may be critical if recharge from the rivers occurs along reaches underlain by the White Sand series or if such recharge should occur in the future at times of greater ground-water draft. Data on the maximum known inland advance of brackish waters in the coastal streams was supplied by Mr. C. S. Ridley, Assistant Director, Drainage and Irrigation Department, as follows:

River	*Inland Extent of brackish water (miles)*	*Extends to outcrop of White Sand series*
Essequibo	40	Possibly near mouth.
Demerara	28	Yes.
Mahaica	12	No.
Mahaicony	12	No.
Abary	20	No.
Berbice	35	Possibly.
Canje	10	No.
Courantyne	No data.	No data.

In summary intrusion of brackish water upstream in several of the major rivers could be a potential source of recharge of poor-quality water into the White Sand series and into the aquifers of the coastal artesian basin. However, the degree of hydraulic continuity between the river waters and the deep aquifers is not known. It is possible that the intermediate clay unit, if present and if sufficiently impermeable in the recharge area, would prevent any significant recharge from the rivers in the stretches where they are brackish.

SURFACE-WATER FEATURES

RUNOFF

The coastal rivers, where they cross the White Sand series, are a potential source of recharge to the aquifers in the coastal artesian basin. If in the future the water levels in the recharge area are drawn down substantially, recharge from streams will become a principal source of supply. Thus, long-term records of runoff are essential to any comprehensive appraisal of the water resources of the coastal plain and of the Colony as a whole.

In 1956, a total of 13 stream gages were in operation in the coastal rivers. Seven of these have been operated for 6 to 10 years by the Demerara Bauxite Co. Three of the seven are gaged in cooperation with the Drainage and Irrigation Department, and four are gaged for their own information; all are operated in connection with a study of the possibility of developing hydroelectric power. Table 12 is a summary of the runoff at these stations, the locations of which are shown on plate 1.

The six remaining gages have been operated since 1955 by the Drainage and Irrigation Department at the mouths of and at points several miles upstream on the Mahaica, Mahaicony, and Abary Rivers (pl. 1) in connection with studies of flood-control works along the rivers and of the supply available for the proposed interstream water conservancies to be constructed 5 to 10 miles inland. No records had been computed at the time of this study. However, miscellaneous estimates of the discharges of several of the streams, made near the coast by the Drainage and Irrigation Department during the wet and dry seasons, show the following results:

River	*Estimated flow (cubic feet per second)* Wet season	Dry season
Essequibo	Not estimated; largest river in the Colony.	
Demerara	13,000	1,000
Mahaica	1,700	700
Mahaicony	1,900	700
Abary	1,100	700
Berbice	Not estimated; may be larger than Demerara.	
Canje	1,900	130
Courantyne	Not estimated; probably larger than Demerara.	

TABLE 12.—*Summary of runoff at seven gaging stations in British Guiana, 1946–5*

[From records at the Drainage and Irrigation Department]

River and location (fig. 1)	Drainage area (square miles)	Records continuous since—	Monthly mean discharge (thousands of cfs)					Annual runoff	
			Maximum		Minimum		Average	Millions of acre-feet	Acre-feet per sqare mile
			Date	Flow	Date	Flow			
Cuyuni River at Kamaria Falls	19,275	1946	January 1950	124	April 1952	5.5	48	34.8	1,810
Potaro River at Tumatumari Falls [1]	2,295	1946–54	February 1953	42	March 1947	2.5	18	12.9	5,390
Demerara River at Great Falls	1,008	1949	June 1956	8.9	April 1952	.5	3.4	2.5	2,460
Mazaruni River at Apaiqua	5,350	1949	do	83	March 1952	6.6	32.2	23.3	4,360
Demerara River at Saca	1,623	1949	July 1951	12	April 1952	1.1	5.2	3.8	2,330
Essequibo River at Plantain Island	26,517	1949	June 1956	253	December 1951	19	100	71.8	2,710
Potaro River at Kaieteur Fall	1,128	1949	do	25	March 1951	.9	8.4	6.0	5,340

[1] Dam and hydroelectric plant under construction since 1954.

Although the estimated flows probably are very crude, they show the order of magnitude of the surface-water supply on the coastal plain. Obviously, for any planning or engineering works these estimates are wholly inadequate.

SEDIMENT DISCHARGE

It is understood that no sediment-discharge stations or studies are being made on any of the major rivers, even though one dam is being constructed. If the sediment load is large, the effectiveness of these structures may be impaired to a considerable extent. Accordingly, at least a reconnaissance-type sediment investigation should be considered in which periodic sediment-discharge measurements would be made at or near the present stream gages and at selected stations on a number of principal streams.

Stream-gaging personnel, if provided with sediment-sampling equipment, could collect occasional sediment samples during low-water periods and during each measurement in high-water periods for analysis to determine the concentration of sediment. The cost of such a program would be modest and the knowledge gained would be of considerable help to the engineers in planning future dams on the major rivers.

In the files of the British Guiana Geological Survey Department, notes dated November 28, 1916, by J. B. Harrison describe sediment samples taken from eight sites at the mouth of the Demerara River. The locations of the sites, the river discharge, the date, and depth of sampling are not known. The analyses of sediment by volume, in parts per million, were 365, 1,590, 6,790, 4,330, 1,730, 1,460, 550, and 1,230.

CONCLUSIONS

The principal conclusions that can be drawn from the brief study of the available well records, the several geologic and well reports, and the reconnaissance pumping tests are enumerated below.

1. The shallow upper sand unit of the White Sand series in large part contains artesian water. The water is of poor quality along the coast and therefore is not a suitable source of supplemental water supply. Farther inland it may yield potable water, and there it might be tested when the need arises.
2. The deep "A" sand unit of the White Sand series furnishes water to the existing 200 flowing wells, most of which are within 5 to 10 miles of the sea coast where 90 percent of the population lives.
   (a) The artesian water of the "A" unit is confined beneath the intermediate clay unit of the White Sand series. The principal sources of recharge are infiltration of rain and seepage loss from streams in the outcrop area south of the coastal plain. Some of the water discharged from wells may be replaced by landward movement of water in the seaward part of the aquifer.

(b) The initial head in wells in the "A" unit in the years 1926–38 averaged about 13 feet above the land surface. Head measured in 1954 in individual wells, while all other wells were flowing, averaged about 9.5 feet; the measurements suggest an average head decline of 3.5 feet. This apparent decline is greater than the true decline because of mutual interference effects. The true head decline could be determined only if all wells were turned off for several weeks or longer so that near static heads could be measured.

(c) The flow from individual wells in 1954–56 ranged from a few to nearly 400 Igpm and for all 200 wells totaled about 20,000 Igpm. The tested flows in 1954–56 were about 20 percent less than the initial tested flows. The decrease is due in part to mutual interference between wells and possibly in part to mechanical difficulties in the wells, such as partial clogging. In 1954 the average specific capacity of 158 wells averaged about 11 Igpm per foot of drawdown.

(d) Pumping of the coastal wells may be undesirable because (1) the threat of sea-water intrusion would be increased, (2) the head differential created between the upper sand and the "A" sand might cause downward leakage of brackish water to the "A" sand and consequent contamination, (3) the cost of purchase, operation, and maintenance of pumping equipment would be substantial, (4) nearby wells in time would cease to flow, and (5) any marked lowering of head might cause land subsidence (Poland and Davis, 1956), which would result in additional expense in the raising of sea defenses and flood-control works.

(e) If additional wells are completed in the "A" sand, the flows and heads in existing wells can be expected to decline somewhat because of mutual interference. Owing to the possibility of sea-water intrusion into the coastal wells, it is believed that other sources of supply should be considered, as described below, to supplement the present rural supply derived wholly from the "A" sand.

(f) Aquifer coefficients for the "A" sand in the Georgetown area are estimated to be: transmissibility 180,000 gpd per foot, field permeability 1,800 gpd per square foot, and storage 0.0002. Additional tests should be made along the coast to refine or support these estimates for use in future quantitative groundwater studies.

3. A untested aquifer or group of aquifers several hundred feet deeper than the "A" sand was noted in electric and drillers' logs of two wells in the Georgetown area and the Rose Hall test hole near

New Amsterdam; these beds are worth exploring as a possible additional source of artesian ground-water supply.

4. Because the irrigation of crops requires large amounts of water, the use of ground-water supplies on a substantial scale near the coast for this purpose would result in depletion and possible salt-water contamination of the present ground-water supply.
5. The scope of the water conservancies now being planned for irrigation and flood control might be extended to include public water supplies for the coastal area in much the same manner as the East Demerara (Lamaha) Water Conservancy is used in large part to supply the city of Georgetown.
6. Gaging stations should be installed on the principal ungaged streams to provide the necessary information on the available surface supply, for construction of flood-control works, dams, highway structures, and water conservancies, and eventually for forecasting flood stages in the coastal area. A reconnaissance sediment-discharge program could be incorporated with the stream gaging to provide essential information on the engineering of hydroelectric, flood-control, and water-supply dams.

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PREPARED IN COOPERATION WITH
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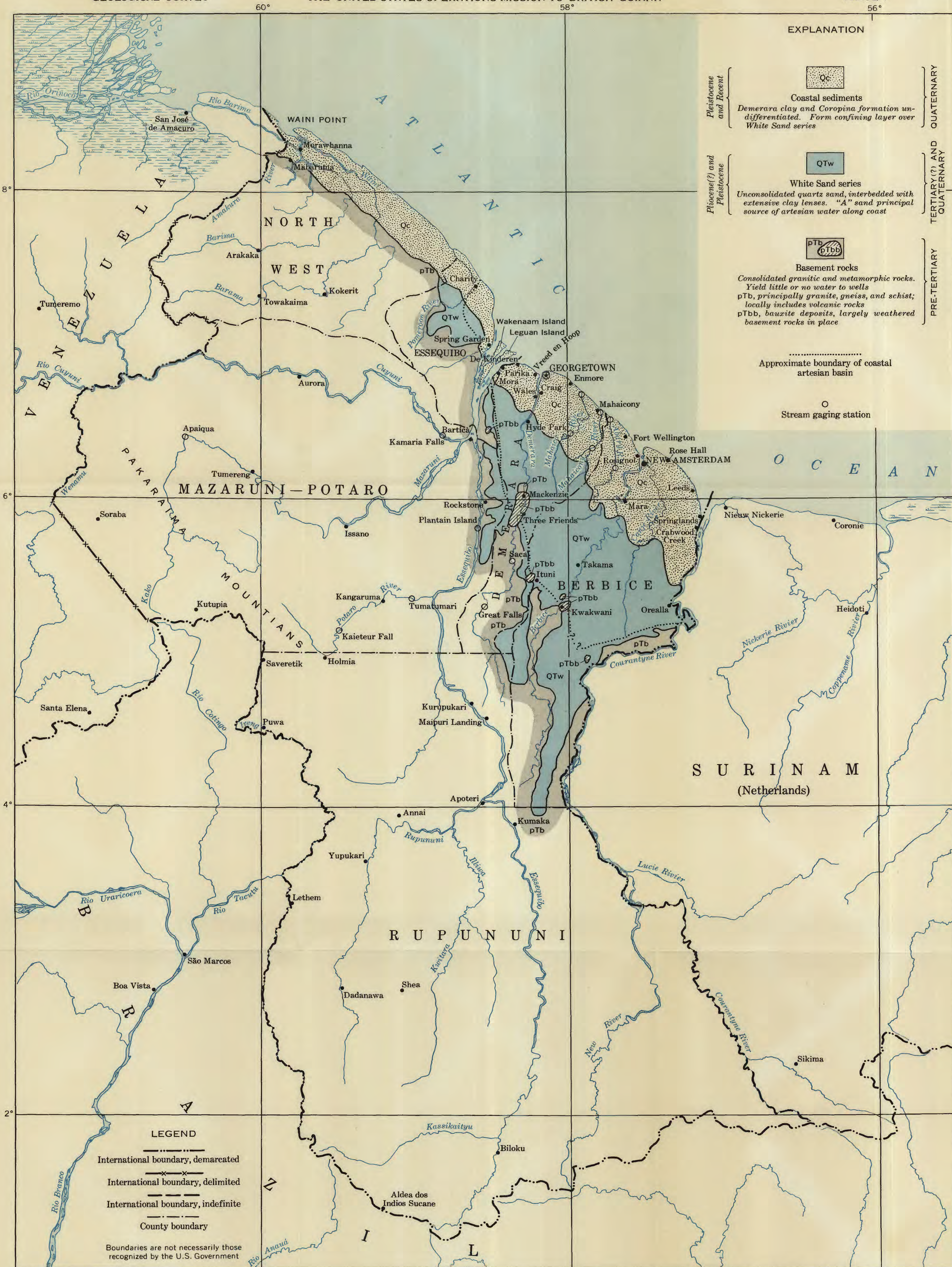
AND UNDER THE AUSPICES OF
THE UNITED STATES OPERATIONS MISSION TO BRITISH GUIANA

WATER-SUPPLY PAPER 1663-B
PLATE 1



Base map from World Aeronautical Charts; 1:1,000,000; Aeronautical Chart and Information Center, US Air Force; various dates

Geology after Stockley (1954)

MAP OF BRITISH GUIANA SHOWING GENERALIZED GEOLOGY OF THE COASTAL BASIN

SCALE 1:2 000 000

25 0 25 50 75 100 MILES

25 0 25 50 75 100 KILOMETERS