SEWERAGE PROGRESS IN BOGOTA, COLOMBIA

by

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DESCRIPTION OF THE CITY

Colombia, located in the northwest corner of South America, is closer to the United States than any other South American country. As shown on Fig. 1, Bogota, the capital, is in the mountainous interior of the country, only three hours by jet from Miami. It is situated on a high plateau called the Sabana in the eastern range of the Andes at an altitude of about 8,500 ft above sea level and about 4° north of the equator. The Sabana itself is the site of a prehistoric lake surrounded by mountains which rise steeply another 3,000 ft immediately east of the city.

The Rio Bogota is the principal watercourse and only outlet of the Sabana, and the water supply for Bogota is obtained from this river, some 20 miles upstream. The river meanders sluggishly through the flat plains of the Sabana until it reaches control gates at Alicachin, which is located about 10 miles downstream from Bogota. Several miles below the gates, which control river levels for power generation purposes, lies the Tequendama Falls where the river pours over a 480 ft cliff into a lush tropical region. All waste water from Bogota passes untreated over these falls. The climate of Bogota is temperate the year around, with two distinct rainy periods, principally during the months of April and November. There is considerable variation in the occurrence and amounts of rainfall from place to place throughout the Bogota area.

During the rainy seasons, heavy thundershowers occur often at midday. Such storms usually occur over the city with surface winds from the southwest, the direction of the falls. These air currents are forced upwards on the steep ridges behind the city and the prevailing northeast winds then carry the thunderheads back over the city. The average annual rainfall on the plateau is about 36 inches, with over 80 inches on some of the higher elevations in the mountains and about 15 inches in areas several miles southwest of the city.

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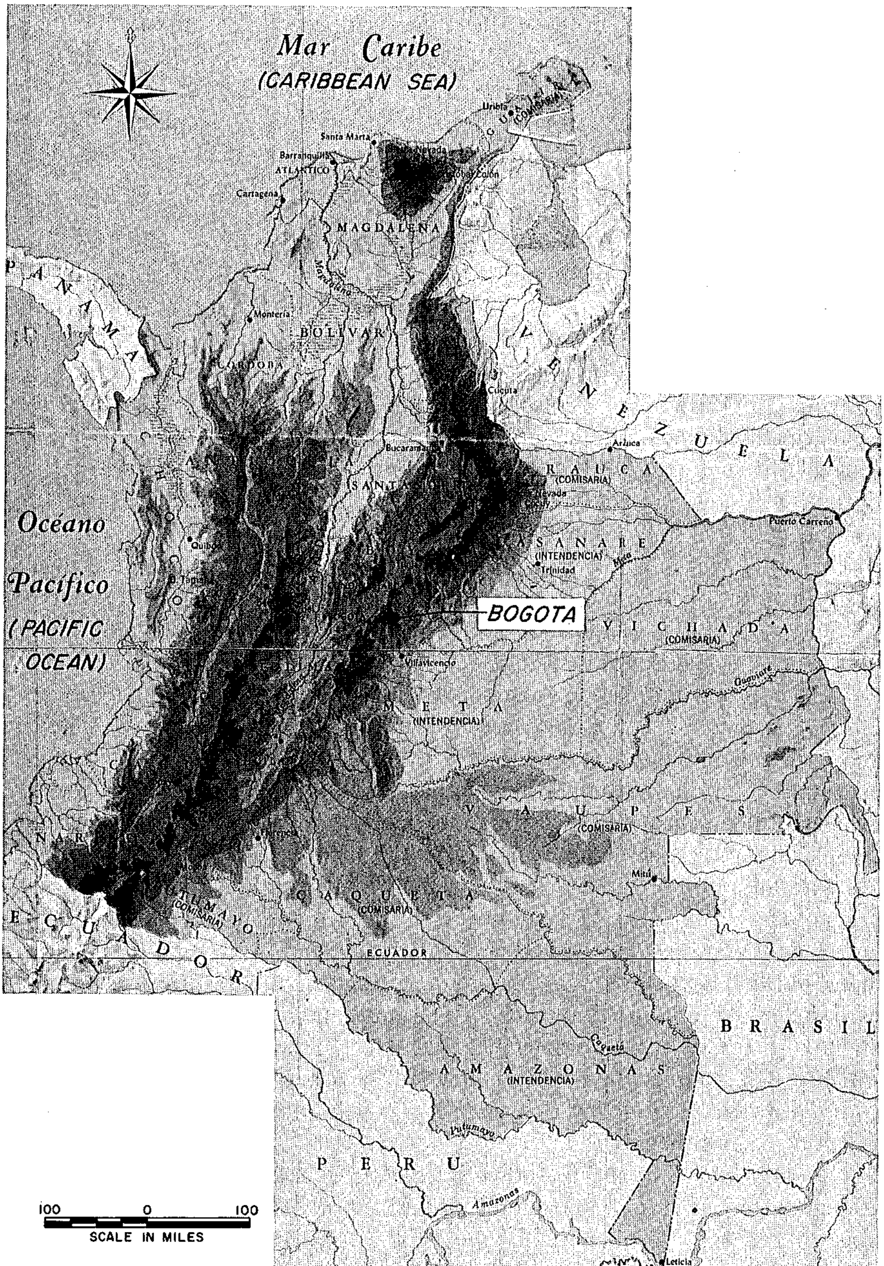

Fig. 1 — Map of Colombia

Portions of the city built on the lower slopes of the mountain range bordering the city on the east have generally hard rocky soil. The lower and more level sections of the city, which are in the area of the ancient lake, generally have soils consisting of organic silt and clay near the surface to clays with some layers of loose gravel and clayey sand at lower levels. The water table is located at depths of between 6.6 and 26 ft.

NEED FOR THE MASTER PLAN

Bogota, like most Latin American cities, is in the midst of a population explosion with ever-increasing sewage flows and worsening stream conditions. These factors, coupled with severe storm-water drainage problems and overflows of mixed sewage and storm water, result in serious hazards to public health throughout the Bogota Sanitary District. The Master Sewerage Plan for Bogota, completed in 1962, provides for a feasible program of staged construction with the goal of eliminating these hazards. Construction of the First-Stage project began early this year, and the long-range program, consisting of five stages, may take about 15 years to complete.

There are two objectives in the Master Plan for the disposal of sewage: (1) Protection of the public health, and (2) elimination of odor nuisances. The most important of these of course is the protection of the public from infection by disease organisms present in sewage.

In 1960, the Empresa de Acueducto y Alcantarillado de Bogota (Bogota District Water and Sewer Department) engaged Camp, Dresser & McKee and C.I.S. (Compania de Ingenieria Sanitaria), a Colombian sanitary engineering firm, to make engineering studies, and to develop a master plan for the disposal of sewage and storm water from the Bogota Sanitary District, comprising an area of approximately 46,000 acres. In 1964, after completion and adoption of the Master Plan, the First-Stage Feasibility Study was prepared by Camp, Dresser & McKee for the Empresa in accordance with the requirements of the United States Agency for International Development (AID). This study was prepared in Bogota with Empresa engineers working under our direction. The feasibility study recommended a First-Stage Construction program, consisting of canals and intercepting sewers which, when completed, will form a part of the long-range Master Plan. The author lived in Bogota for two years during the preparation of this study and construction plans.

The First-Stage program, shown by means of dotted lines on Fig. 2, is now under construction, and the Second-Stage program is under consideration. In general, the objective of the First and Second-Stage Construction programs is to construct collectors, canals and appurtenant facilities serving

Fig. 2 — Plan of Bogota Master Sewerage Program

the greatest problem areas which are above flood water levels in the Rio Bogota. Detailed planning of future stages of construction depends on whether the Rio Bogota channel is to be improved.

To prevent infections, closed conduits are proposed for all sewage, whether or not it is mixed with storm water. To eliminate the odor nuisance, it is recommended that future dry weather flows of sewage be conveyed in closed conduits to chlorination stations and thence to stabilization lagoons before it is discharged to open stream channels at locations well removed from densely populated areas.

PRESENT SANITARY CONDITIONS

There are well over 100 miles of open drainage ditches within the Sanitary District which carry mixed sewage and storm water. High water levels in the Rio Bogota and heavy storms over the city now cause the lower reaches of the main channels of the Rio Salitre and the Rio Fucha to overflow their contents of combined sewage into adjacent low-lying areas. Since most of the area is flat, these areas are quite extensive. Children play and animals roam in these areas, as shown on Figs. 3 and 4, and as a result, disease may be readily contracted and transmitted. Many new settlements have recently developed around the city as a result of heavy immigration from rural areas. Such settlements often are without water or sewer service.

In general, improvement in food sanitation, personal hygiene, sanitary conveniences, and sewage disposal has not kept pace with the improvement in quality of the public water supply. In 1961, the reported rate of cases of diarrhea and enteritis in children under 2 years of age was almost 12,500 per 100,000 children. It is reasonable to assume that the rate would be much higher if the number of unreported cases was known. Other waterborne diseases, such as amoebic dysentery, shistosomiasis and infectious hepatitis are also commonly experienced by members of the general population and foreigners staying in Bogota.

EXISTING SEWERAGE AND DRAINAGE SYSTEMS

It is estimated that about 1 million inhabitants are served by the existing sewerage system through over 100,000 household, commercial, industrial, institutional and public connections. There are approximately 27,600 acres of built-up area in the Sanitary District of which about 24,700 acres are presently sewered. Of these 24,700 acres, approximately 14,800 acres are presently served by combined sewers, and the remainder by a separate system of sanitary sewers. As in the United States, areas served by the existing separate systems consist for the most part of more recent housing

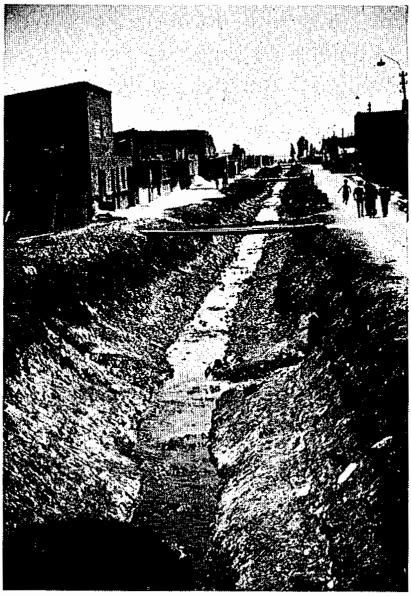

Fig. 3 — Unsanitary condition in Residential Area

Fig. 4 — Typical Conditions along Rio Salitre

developments. All new sewer systems are constructed on the separate plan. Separation of existing combined sewer areas is not recommended because its estimated cost is almost double the cost of collecting and treating combined flows.

DESIGN CRITERIA

Sanitary Sewers

Figure 5 shows past and projected population and water consumption trends for Bogota. Based upon evidence available at the time of the preparation of the Master Plan, it was expected that a population of approximately 3,200,000 might be attained by the year 1985. It may be seen from Fig. 5 that actual population increases from 1960 to the present time have exceeded those which were projected because of the heavy immigration mentioned above and a high birth rate. It thus appears that the projected population of 3,200,000 may be exceeded before 1985 if the present rate of growth continues. Such a population increase means that the consumption of water and the discharge of sewage will increase substantially, thus increasing the urgency for water and sewer facilities. There is very little use of the public water supply for lawn sprinkling, air conditioning and industrial water, or fire protection.

It is anticipated that by the design year of 2010 the entire population will be served with potable water in such a manner that water consumption will more closely reflect the water requirement of the area than it does at present. At the present time, many homes, particularly in poorer areas, are not directly served with water, and inhabitants must utilize the nearest public faucet. Approximately 10 per cent of the inhabitants of Bogota are supplied with water from such unmetered public fountains.

The average per capita sewage flow for the adequately served residential population is estimated to be about 62 gpcd. It is estimated that Bogota now has a total population of about 1,700,000 with an annual average sewage flow of about 88.2 mgd, or about 52 gpcd. It is estimated that between the years 1985 and 2010 the total water consumption and sewage flow for the Bogota Sanitary District will reach about 315 mgd, or about 97 gpcd.

Bogota has been painstakingly zoned for various land uses by the Bogota District Planning Department. Population densities for tributary areas were estimated, based upon these land uses. The average population density in residential areas by the year 2010 is estimated to be about 100 persons/acre. This results in an average per acre sewage flow by the year 2010 of approximately 9,800 g/acre/day.

Sewage flows have been based upon estimates of probable fixture unit

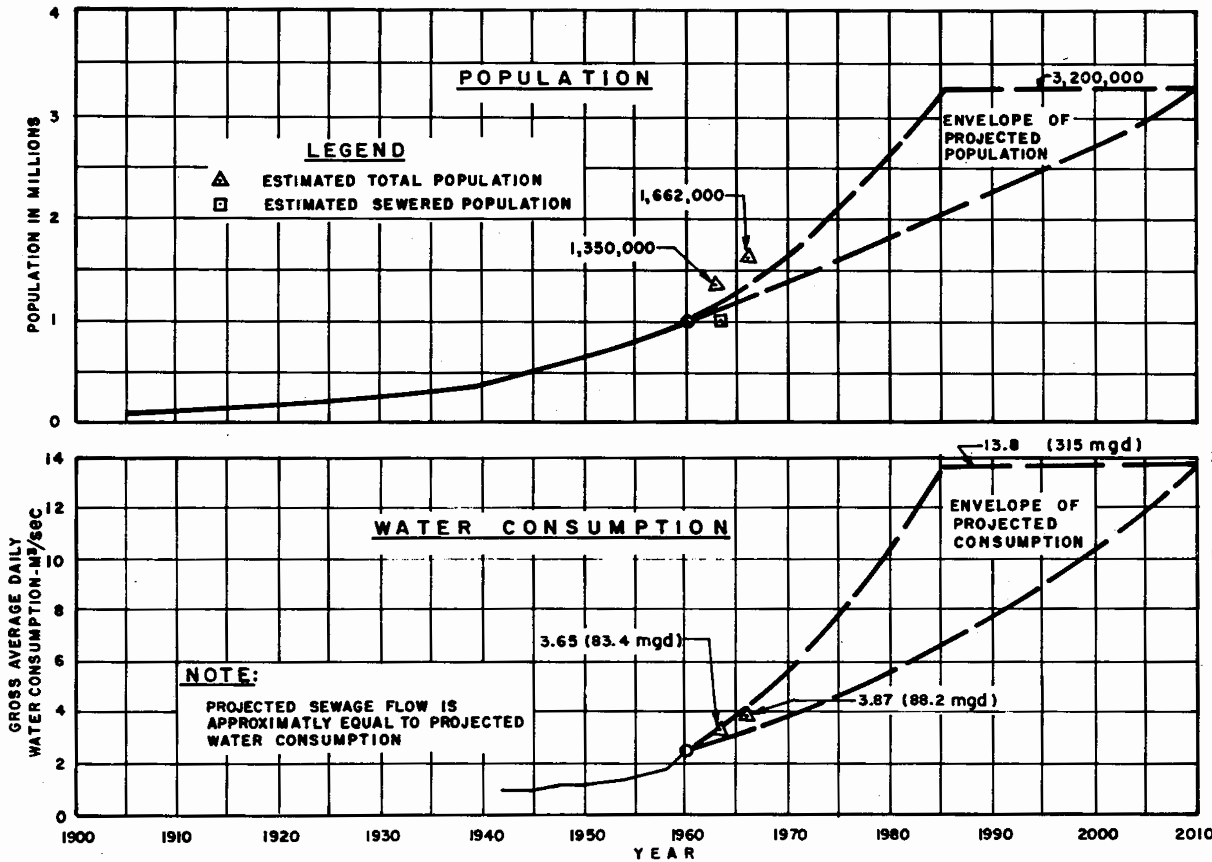

Fig. 5 — Population & Water Consumption Trends for Bogota Sanitary District.

densities for small areas, water consumption data and from gagings taken in various parts of the existing sewerage system. The flows are based upon 90 percent of saturation population for areas of 1,235 acres or more for design purposes.

Land use zones were arranged into six groups: A,B,C,D, E and F. The land use zones having the least population density are grouped under group A, while those having the highest population density are shown under group D. Groups A, B and C comprise most of the area to be occupied by residential water users. Zoned areas in Groups E and F are considered individually.

The design average flow for tributary areas of 1,235 acres and greater has been estimated at 7,400 g/acre/day for group A; 10,600 g/acre/day for groups B and C, and 16,600 g/acre/day for group D. Most of the tributary areas entering into the design of the Master Plan works are greater than 1,235 acres.

Peak flows of sanitary sewage for design purposes have been estimated, based upon the curves shown in Fig. 6. The curves on this figure were developed from work done in many communities in the United States and from curves found in the revised ASCE Manual of Engineering Practice No. 37, currently being published. Results of gagings taken throughout the Bogota sewerage system are shown.

The estimated rates of ground water infiltration are added to the estimated dry weather flow of sanitary sewage for the design of all sanitary sewers and interceptors. Our estimates are based upon extensive construction and maintenance experience of the Empresa throughout the Bogota area, upon observations of many exploratory test pits and upon soil analyses conducted by the Empresa. The zones of lowest infiltration lie in the higher elevations of the city near the base of the mountains, and the zones of highest expected infiltration lie in the lowlands toward the west and nearer the Rio Bogota. The estimated maximum infiltration rates in existing sewers vary between 1,850 and 3,700 g/acre/day. All sewers and interceptors proposed in the Master Plan will have preformed rubber joints to reduce rates of infiltration.

Sanitary sewers and dry weather interceptors for Bogota are designed to carry simultaneously estimated peak sanitary sewage flow, ground-water infiltration and industrial waste water flow for the design period. The design capacities of the sewers and interceptors flowing full are obtained by dividing the estimated peak flow by the following factors:

0.6 for pipes 8 to 21 inches in diameter
0.7 for conduits 24 inches to 47 inches (1.20m) in diameter
0.9 for conduits 49 inches (1.25m) and larger in equivalent diameter

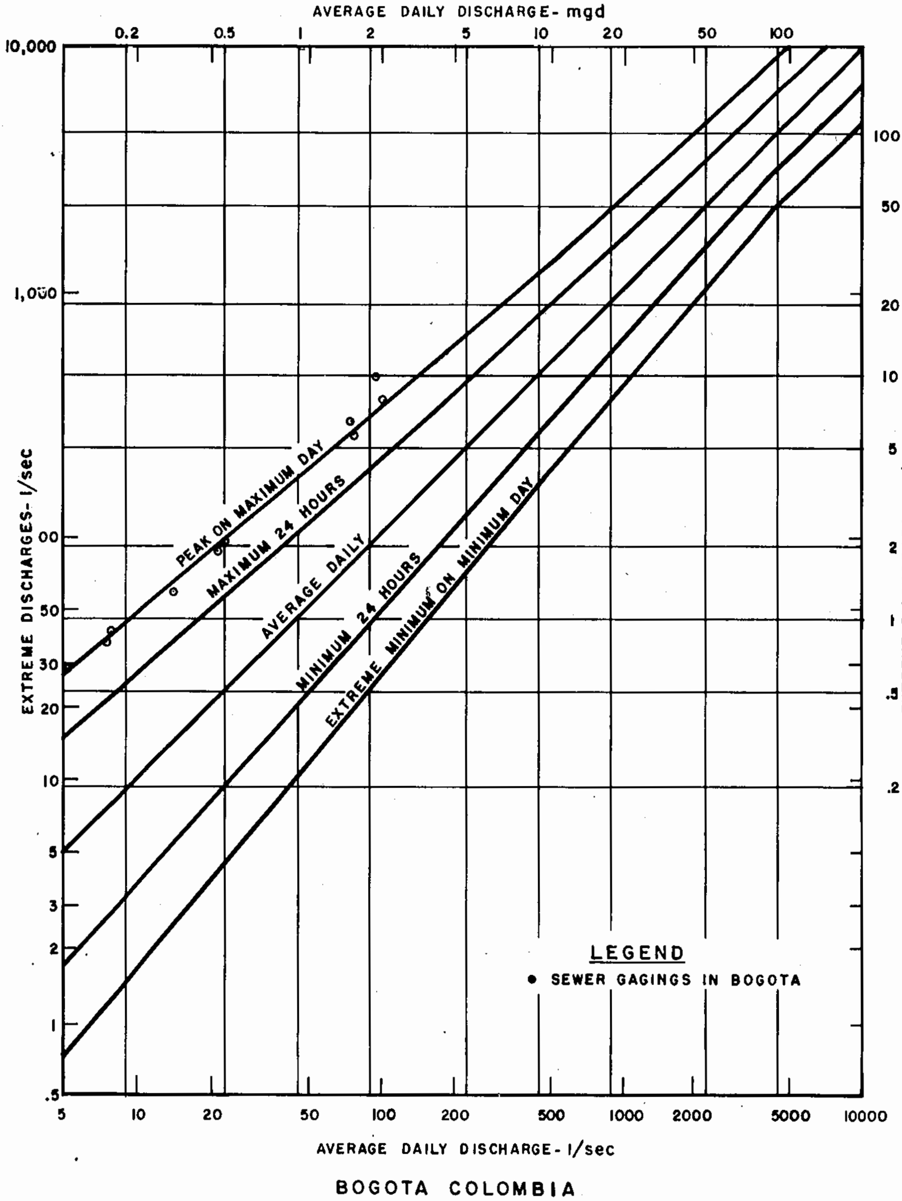

Fig. 6 — Relation of Extreme Discharges to the Average Daily Discharge of Sanitary Sewage

(It should be noted that pipe is manufactured locally according to the English system of units up to 36 inches in diameter, and according to the metric system from 1.00 m.

For pipes from 8 to 15 inches in diameter, a Manning's "n" value of 0.014 is used with slopes sufficient to produce scouring velocities of not less than 2 fps at flowing-full capacity. For pipes and conduits 18 inches in diameter and greater, an "n" value of 0.013 is used.

In addition to the above criteria, conduits with diameters greater than 47 in. (1.20m) are investigated to determine critical depth, particularly in areas of steep topography.

Conduits for Mixed Sewage and Storm Water

To protect the people from water-borne diseases, dry weather flows of sewage from existing combined sewer areas are to be received at points of overflow by interceptors designed in accordance with the criteria for the design of sanitary sewers. The intercepted sewage will ultimately be conveyed to chlorination stations and treatment works designed for the dry weather flow only. Open ditches and streams flowing through the combined sewer area, which receive overflows of mixed sewage and storm water, will be paved, and provisions will be made for enclosing such streams in the future. These paved streams or canals will carry flows to future chlorination stations prior to discharging to the Rio Bogota. These stations will be located on the Rio Fucha, Rio Salitre and Rio San Francisco.

The design of conduits carrying mixed sewage and storm water is simplified by estimating the rates of storm water runoff only, as discussed below. The size of rainstorm used for the determination of the design runoff for a particular conduit depends upon the damage which may result from an overflow or flood. The size of the rainstorms used for design are designated in terms of the frequency of their occurrence in years, as shown in Table 1.

Precipitation has been recorded in Bogota since about 1806. Continuous records have been made since 1922, from which we determined the amount of precipitation for five-minute intervals and developed intensity-duration curves.

On December 4, 1966, a severe rainstorm occurred in the mountains east of the city. Comparison of the rainfall intensity and duration for this storm with curves based on previous records indicated a recurrence frequency of about 5 years. Storm runoff velocities from this storm of about 15 fps were observed in downtown Bogota streets, resulting in severe damage to property, as indicated in Fig. 7.

TABLE 1
DESIGN STORM FREQUENCIES OF CONDUITS
FOR VARIOUS TYPES OF AREAS

TYPE OF AREA	DESIGN RAINSTORM RECURRENCE FREQUENCY IN YEARS			
	TYPE A CANAL		TYPE B CANAL	
CONDUITS FOR UNCHLORINATED STORM WATER OR CHLORINATED MIXED SEWAGE AND STORM WATER	Pipe or Closed Conduit	Usable Channel	Paved Portion	Usable Channel
Located in Low Value Residential Areas	3	10	3	10
Located in Multiple Family & High Value Residential Areas; Medium Value, Residential, Commercial and Industrial Areas	5	20	5	20
Located in Principal Administrative Areas; High Value Commercial and Industrial Areas	10	40	5	40
Serving Tributary Area of over 1000 Hectares	—	20	5	20
Acequias - Storm Water Interceptors	—	40	10	40
Spillways from Acequias or Open Channels across Slopes	—	100	10	100
CONDUITS FOR UNCHLORINATED MIXED SEWAGE AND STORM WATER				
Located in Low Value Residential Areas	5	10	3	10
Located in Multiple Family & High Value Residential Areas; Medium Value, Residential, Commercial and Industrial Areas	10	20	5	20
Located in Principal Administrative Areas; High Value Commercial and Industrial Areas	20	40	5	40
Serving Tributary Areas of over 1000 Hectares	—	100	10	100

NOTE: All open channels for mixed sewage and storm water upstream from proposed chlorination stations are designed to be covered in the future.

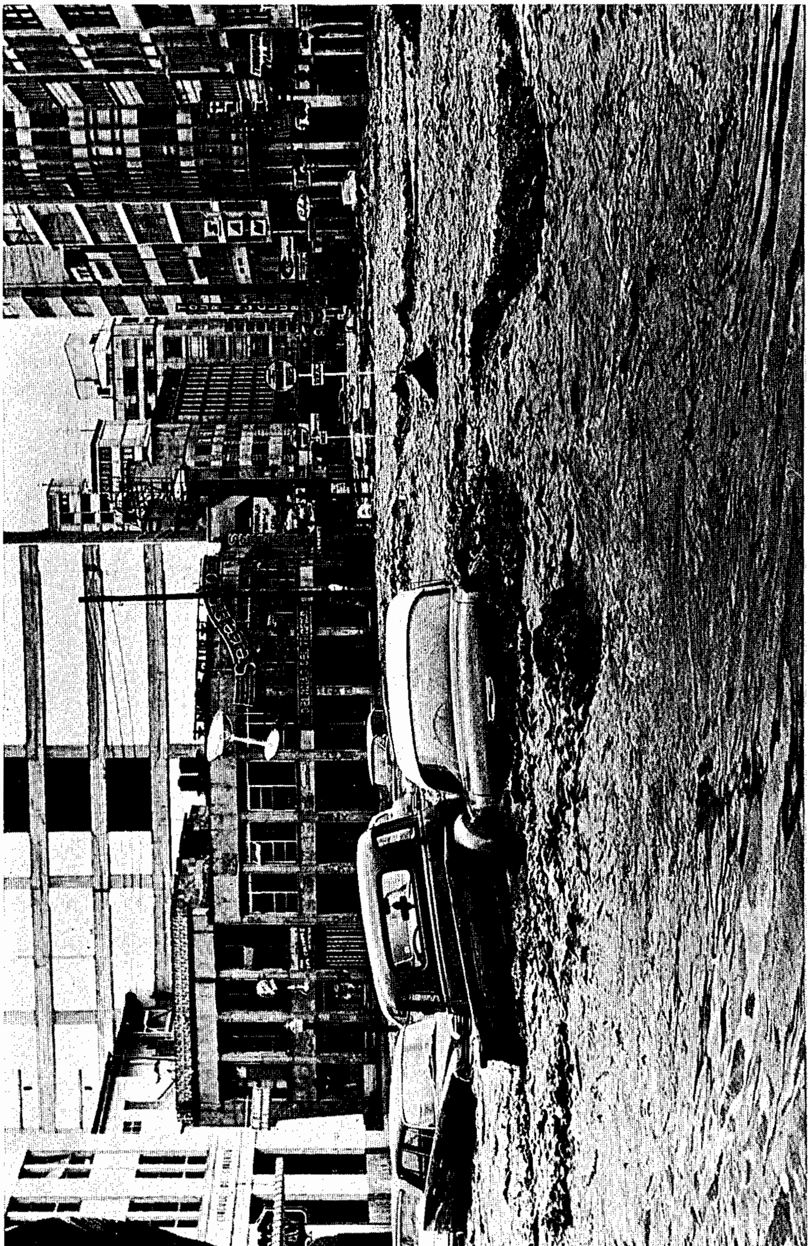

Fig. 7 — Downtown Street Scene during Storm of December 4, 1966

Rainfall intensities over large drainage areas are modified for design purposes by the use of reduction factors inasmuch as the average intensity of rainfall over a large area is considerably less than the intensity shown by the rain gages. These factors are supported by studies made by the U.S. Weather Bureau and others. Storm water runoff in the Bogota Sanitary District was estimated by the "Rational Method". Horner coefficients of runoff were adapted for use in Bogota by assuming that the intense rainfall starts after the ground has been wetted for ten minutes and by applying the "zone principle" to compute the average coefficients throughout the drainage area under investigation. Percentages of relative imperviousness were estimated for different land uses. The time of concentration of flow, which is the time of flow from the most remote point of a tributary area to the loading point on a conduit, was determined for estimated time for surface runoff and flow time in mountain streams, swales, ditches, gutters and conduits.

During the preparation of the Master Plan, many different canal sections were considered. A trapezoidal section (Type B) with paved and sodded portions was chosen as being most suitable and requiring very little structural design. A rectangular section (Type A) is considered for use in locations where lateral clearance is a problem. The recommended arrangement of the trapezoidal canal and interceptors is shown on Fig. 8. All pipes and closed conduits for mixed sewage and storm water are designed to flow full.

The various materials and Manning's roughness coefficients "n" which are used are listed below:

Conduit Size and Shape	*Material*	*Manning's "n"*
12 - 15 inch pipe	Vitrified clay	0.014
18 - 30 inch pipe	Vitrified clay	0.013
Pipes larger than 30 in. (0.76 m)	Reinforced concrete	0.013
All sizes and shapes	Brick	0.016
Type A or B canals	Reinforced concrete	0.013
Type A or B canals	Brick or soil cement	0.016
Type A or B canals	Sodded slopes	0.035

The effective "n" value for a full open canal with two different lining materials, such as concrete and sod, is computed from the following formula:

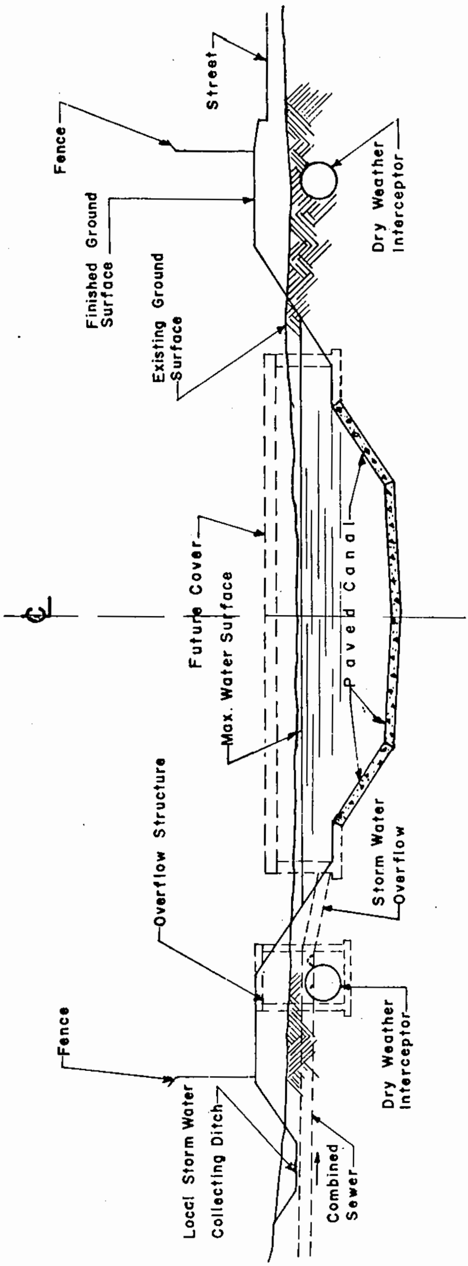

Fig. 8 — Recommended Arrangement of Canal and Interceptors

$$n = \left(\frac{P_1 n_1^2 + P_2 n_2^2}{P_1 + P_2} \right)^{1/2}$$

Where n_1 is the "n" value for the concrete portion, n_2 is the "n" value for the sodded portion, P_1 is the wetted perimeter of the concrete portion, and P_2 is the wetted perimeter of the sodded portion.

The slope of the energy line for all canals or other conduits for mixed sewage and storm water is computed to provide mean velocities flowing full of not less than 3.3 fps. Maximum design velocities are governed by the relation of critical depth to the depth of flow under consideration. Special junction and transition structures are designed where flows pass through critical depth, where a conduit discharges to one of larger size or where larger flows enter a conduit. The Froude Number at the design flow must be less than 0.9 or more than 1.1 in order to avoid the unstable flow and high friction factors which develop at or near the critical depth. In addition, losses are computed in cases where high velocities will occur on canal curves.

FIRST-STAGE CONSTRUCTION PROGRAM

The First-Stage Construction program consists of the construction of canals, intercepting sewers and collectors in various locations in the city. It includes the construction of about 12 miles of canals having bottom widths of from about 6.6 ft to over 115 ft, and the construction of about 22 miles of intercepting sewers and collectors ranging in size from 10 in. to over 10 ft. in equivalent diameter.

The First Stage has been arranged for construction into 22 separate contracts with the first contract awarded in December 1966. At present, 21 contracts have been awarded, all of them to Colombian contractors, and plans are being prepared on the last one. The total value of the 21 construction contracts plus the estimated cost of Contract 22 is about 13.7 million dollars, as shown on Table 2, based on an exchange rate of 9 pesos to the dollar. The various contracts in the First Stage are shown by numbers and dotted lines on Fig. 2.

Progress of the construction work is excellent with Contracts 12, 13 and 14 approaching completion. In general, the quality of work being performed is quite high and is improving as both the Empresa and the contractors become familiar with stricter requirements of inspection and construction than hitherto prevailed.

TABLE 2 FIRST STAGE CONSTRUCTION COSTS

Contract No.	*Name*	*Estimated Construction Cost X 10^6*
1	Comuneros I	6.11 pesos
2	Comuneros II	6.99
3	Comuneros III	7.76
4	Albina	3.27
5	Salitre IA	8.73
6	Rio Seco	6.66
7	Boyaca	6.01
8	Rio Nuevo	10.38
9	Còrdoba A	6.56
10	El Cedro	4.15
11	Cordoba B	6.56
12	San Vicente IA	0.88
13	San Vicente IB	2.94
14	San Vicente IC	1.08
15	San Vicente II	1.53
16	Contador	8.62
17	Del Norte	7.97
18	San Francisco A	8.73
19	San Francisco B	8.73
20	San Francisco C	8.73
21	Salitre II	24.57
22	Salitre IB[1]	1.74
	Estimated Total Construction Cost[1]	148.70 pesos = 16.5 million dollars U.S.[2]
	Total Value of Contracts	122.98 pesos = 13.7 million dollars U.S.[2]

NOTES: [1]Contract 22 not yet awarded.
[2]Based on an exchange rate of 9 pesos to the dollar.

CONSTRUCTION METHODS

Circular conduits are constructed of vitrified clay pipe, precast reinforced concrete pipe and brick. Because of the ample supply of unskilled but easily trained labor and low cost (about 1.00 dollar per day for a common laborer), there is a tendency in Bogota to utilize less precast units and labor-saving equipment than in the United States. Brick is readily available, and as a result, brick conduits are being built as part of the Master Plan work, as shown on Fig. 9. Economic comparisons made prior to the awarding of construction contracts indicated that circular brick sections, precast reinforced concrete pipe sections, and cast-in-place reinforced concrete box culvert sections of equivalent hydraulic and structural capacity were about equal in cost. High quality reinforced concrete pipe is produced locally in quantities sufficient to support construction of the Master Plan. Installation of such pipe is shown on Fig. 10.

During the preliminary design phase of the First Stage facilities, it was considered feasible to use precast reinforced concrete canal slabs with temperature steel for the 1 1/2 to 1 (horizontal to vertical) side slopes and cast-in-place concrete for the base. However, tests run prior to construction, as well as subsequent construction experience in Bogota, indicated that casting the concrete side slopes in place on that slope is entirely feasible and results in a quite satisfactory job. Bedding for the slabs on the side slope is simplified by using vertical gravel-filled troughs spaced at about 6.6 ft intervals in the clayey subbase for drainage. The remainder of the slope is covered with a ½ in. to ¾ in. layer of mortar to prevent drying of the clay and provide a good working base. This construction is shown on Fig. 11.

Rectangular conduits are constructed of cast-in-place and precast reinforced concrete. At present, precast reinforced concrete slabs are being used for the side walls of box culverts on two contracts (contracts 8 and 21, as shown on Fig. 12). After these wall slabs are set in place, they are cast into the base slab. Spaces between slabs permit lapping of reinforcing steel to provide structural continuity.

FUTURE CONSTRUCTION PROGRAMS

The total estimated construction cost of the entire Master Plan program, consisting of a grand total of about 75 miles of open and covered canals and 87 miles of intercepting sewers, together with pumping and treatment facilities, is about 85,000,000 dollars U.S.

It is expected that facilities for the treatment of dry weather sewage flows will be constructed as part of the final stage. These treatment facilities were proposed to be stabilization lagoons because of the availability of land and shortage of electric power. Pilot plant studies are now under way to determine the loadings which may be utilized in Bogota. Because of increases in available electric power and the cost of land since 1964, further study appears warranted to determine whether conventional treatment facilities may now be more advantageous than lagoons.

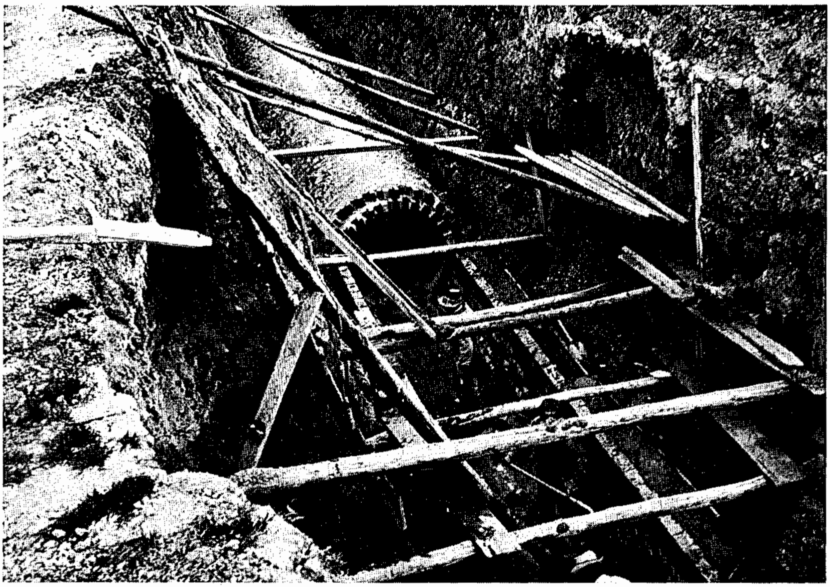

Fig. 9 — Construction of Brick Sewer

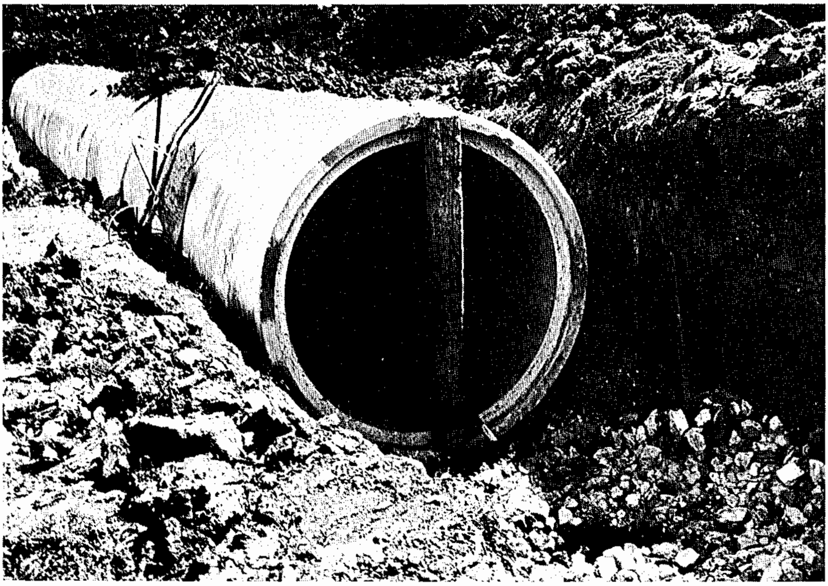

Fig. 10 — Installation of Reinforced Concrete Pipe

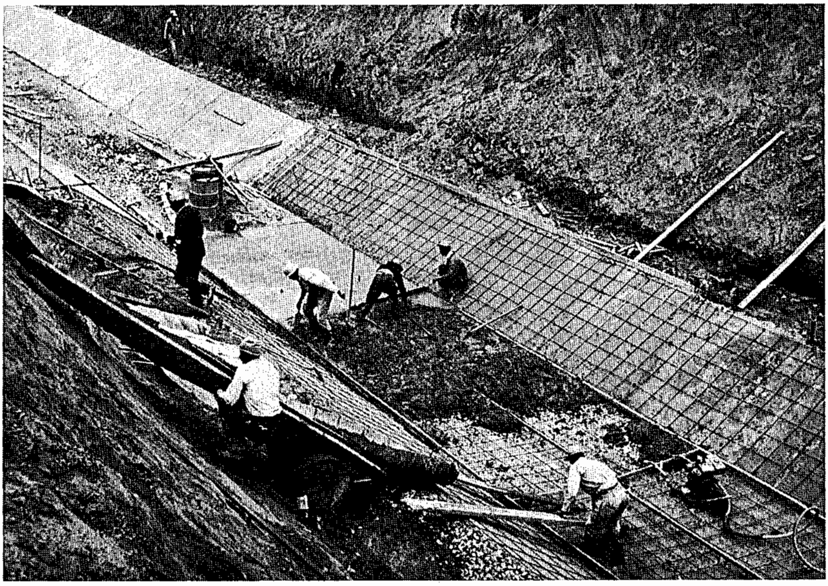

Fig. 11 — Paving Canals of Trapezoidal Cross-Section

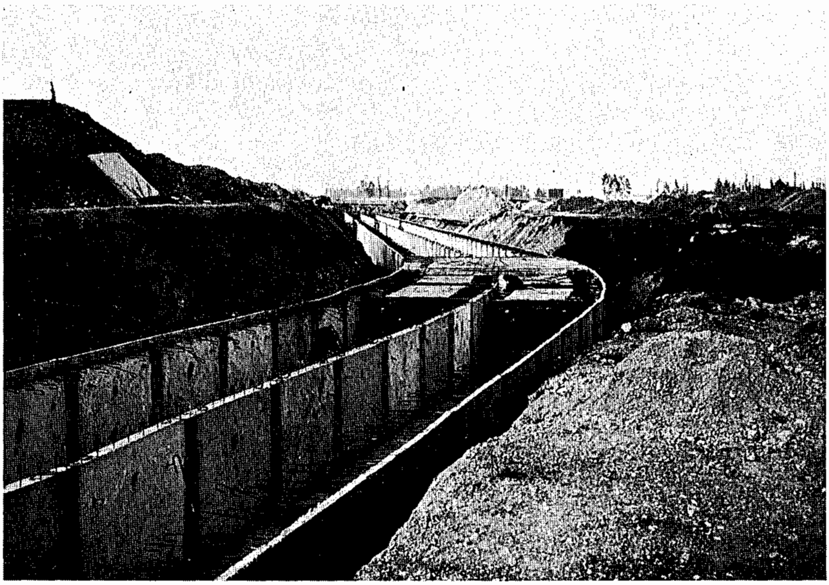

Fig. 12 — Double Box Culvert Canal Section under Construction

CONCLUSION

A Master Sewerage Plan has been developed for Bogota, Colombia which provides a feasible and orderly program for the elimination of serious flooding and water pollution conditions which now exist in the city. At the present time, detailed planning and construction activities to implement the Plan are progressing at a rapid pace. The program effectively utilizes Colombian engineering talent to solve a most pressing public health need.

Based upon work accomplished to date, several conclusions may be drawn:

1. Local (Colombian) engineering talent is of a high order.
2. The generally good quality of construction by local contractors is being improved by their growing familiarity with and use of modern techniques.
3. Low wage scales, coupled with comparatively high material prices, result in the utilization of considerably more manual labor and less mechanized equipment than is the case in the United States.
4. Public awareness of the need for proper sewage disposal and drainage in Bogota is now being followed by energetic efforts by local public agencies to achieve it.
5. United States consultants working in foreign countries must be flexible in their approach to solutions. In particular, it is essential that we recognize that approaches to solving sewerage and drainage problems in the United States may require modification to be fully applicable overseas.
6. Through its adoption of modern engineering practices and construction techniques adapted to local needs, material and labor, Bogota is now progressing toward pollution abatement on a large scale for the benefit of all of its citizens.

ACKNOWLEDGEMENTS

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