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THE PANAMA CANAL.

Part II.

PROJECTS, TECHNICAL NOTES, AND DISCUSSION OF THE HYDRAULICS OF THE CHAGRES RIVER.

PUBLISHED BY
OFFICE OF ADMINISTRATION
ISTHMIAN CANAL AFFAIRS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.

1905.

ISTHMIAN CANAL COMMISSION.

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THE PANAMA CANAL.

Part II.

PROJECTS, TECHNICAL NOTES, AND DISCUSSION OF THE HYDRAULICS OF THE CHAGRES RIVER.

PROJECT RECOMMENDED BY THE COMITÉ TECHNIQUE.

What is known as the Comité Technique, or Technical Committee, appointed by the New Panama Canal Company, after investigations and studies extending over a period of several years, during which time they considered nearly every plan for a canal on the Isthmus of Panama that could be thought of and that did not involve an expenditure of time and money that was prohibitive, arrived at the conclusion that one of the three following plans afforded the most satisfactory solution of the canal problem:

- III. A project with a summit level of 62.31 feet. Estimated cost, \$102,483,000.
- II. A project with a summit level of 97.6 feet. Estimated cost, \$98,816,000.
- I. A project with a summit level of 126.31 feet. Estimated cost, \$94,570,000.

The Committee recommended the adoption of Project II, chiefly because it seemed to enable the definite completion of the Culebra Cut and the auxiliary works at Bohio to be accomplished within the same length of time. It was estimated that the dam and locks at Bohio would require ten years for construction, and it was estimated that the Culebra Cut in Project II would be completed in the same time, whereas it was thought to be doubtful, whether or not, it could be done in that time under Project III. To do so within the time estimated necessary for the completion of the auxiliary works at Bohio would require a large increase in the number of workmen, which it was desired, if possible, to avoid.

Project I was practically eliminated before the report was signed, so that in point of fact, there were only two projects that were finally offered, either of which would fulfill all requirements, but preference was expressed for Project III, provided it should be found in the course of the work that the Culebra Cut could be made as deep as that project necessitated within the time needed for the construction of the works at Bohio. The final decision, however, was left to be determined at a later period, after longer experience on the Great Cut indicated with certainty whether or not the excavation there could be made within the time limit. It was thought that for two or three years the work could go on with advantage, no matter which project might be finally adopted.

In Project III Lake Bohio was to form the summit level of the canal, and it was to be supplied with water from the Chagres River without any artificial feeding device. A second lake was to be created in the upper valley of the Chagres by means of a dam at Alhajuela, the object of which was to hold back a part of the freshets and supply the deficiencies of the dry season. The summit level was reached by a flight of two locks at Bohio, on the Atlantic side; and a similar

flight of two locks at Pedro Miguel, together with a tide lock at Miraflores, on the Pacific side. The total number of locks in this scheme was five.

Project II had a summit level of 97.6 feet and Lake Bohio constituted an intermediate level on the Atlantic side, and a short line between Paraiso and Pedro Miguel, another on the Pacific side. A flight of two locks was to be constructed at Bas Obispo and one lock at Paraiso. The project provided for eight locks in all, four on the Atlantic side for reaching the summit level, and four, including the tide lock at Miraflores, on the Pacific side. Lake Alhajuela was to be created, as in Project III, for taming the Chagres and supplying the summit level. The latter was to be done by means of a feeder extending from Lake Alhajuela to the vicinity of Obispo.

Project I established the summit level at 126.31 feet above mean tide. Lake Bohio remained as in Project II, but the summit level being higher, was reached by means of five locks on the Atlantic side, two at Bohio and three at Obispo; and five on the Pacific side, two at Paraiso, two at Pedro Miguel, and a tide lock at Miraflores. The summit level was supplied from Lake Alhajuela exactly as in Project II.

The canal was to have a width of 98.5 feet in earth and 111.5 feet in rock. In Lake Bohio the width was to be increased to 164.1 feet in earth and 173.9 feet in rock. The depth was to be 29.5 feet. The side slopes varied according to the material through which the cuts were to be made, and some widening was provided for in the bends. In order to enable vessels to pass each other when going in opposite directions several sidings were provided.

A canal of these dimensions, of course, does not afford the same facilities as the one recommended by the Isthmian Canal Commission, which is 150 feet wide and 35 feet deep, with locks also of greater dimensions than those provided in the French projects. In order, therefore, to make the two plans comparable, it is necessary to enlarge the dimensions of the three projects of the Technical Committee to correspond with those of the Isthmian Canal Commission. This increase in dimensions necessitates an increase in the estimate of cost. It is estimated that Project III will cost about \$149,000,000 when made to conform to the increased dimensions; the Bohio dam and Gigante spillway remaining of the same construction as that proposed by the Technical Committee. Project II will cost about \$4,000,000 less, say \$145,000,000. Project I will cost less than Project II, and will probably amount to about \$142,000,000. These figures are approximate only. The Technical Committee regarded about 30 feet as the greatest admissible lift of the locks, and in no case were they to exceed, even at the highest stage of the lake or summit level, 33 feet.

The following is the report of the Technical Committee in full:

**REPORT TO THE NEW PANAMA CANAL COMPANY BY THE INTERNATIONAL COMMISSION
OF ENGINEERS APPOINTED IN ACCORDANCE WITH ARTICLE 31 OF THE BY-LAWS.
DATED NOVEMBER 16, 1898.**

INTRODUCTION.

In accordance with article 31 of the by-laws, the New Panama Canal Company appointed a technical commission of engineers composed as follows:

- Mr. Robaglia, president, general inspector des ponts et chaussees (retired).
- Mr. Bouvier, secretary,^a general inspector des ponts et chaussees (retired).
- General Abbot, Engineer Corps, U. S. Army (retired).
- Mr. Castel, inspector-general of mines (retired).
- Mr. Daynard, chief engineer of Transatlantic Steamship Company.
- Mr. Fargue, general inspector des ponts et chaussees (retired).
- Mr. A. Fteley, chief engineer, aqueduct commission, New York.
- Mr. Fulscher, private counselor to the department of public works of Prussia, formerly technical director of the Kiel Canal.
- Mr. Hersent, civil engineer.
- Mr. Hunter, chief engineer of the Manchester Canal Company.
- Mr. Koch, counselor of public works; director of the Technical Academy of Darmstadt; formerly special member of the imperial commission of the Kiel Canal.

^a The commission of engineers mourns the loss of Mr. Bouvier.

Mr. Jules Martin, general inspector des ponts et chaussées (retired).

Mr. Skalkowski, formerly director of the bureau of mines in the department of agriculture and estates, Russia.

Mr. Sosa,^a chief engineer of the Republic of Colombia.

The commission of engineers has held between February 3, 1896, and September 8, 1898, ninety-seven regular sessions and many informal meetings. It has followed, as it were, day by day, the surveys, the works, and the plans of the company.

Several members visited the Isthmus in the spring of 1898. They brought back valuable data and information which confirmed in every important particular the conclusions to which the commission had already been led by its studies in Paris. In this way have been established with precision the basis and the general plan of a canal with locks, which will fully provide for the needs of navigation between the two oceans, and this within reasonable limits of time and outlay.

The details of this plan will be given further on, but it seems first to be interesting and necessary to indicate what may be called the genesis of the idea, which by progressive evolution from the teaching of the past and the deduction from recent experience have evolved the solution considered by the commission of engineers to be most logical and satisfactory. This will form the subject of the first chapter, the aim of which is to show the varied aspect of an extremely complicated problem and to justify the solution finally reached.

CHAPTER I.—*Discussion of possible solutions and justification of the one adopted.*

Principal problems to solve:

The building of a maritime canal across the Isthmus of Panama encounters, from a technical point of view, two main difficulties. These are, on the one hand, the chain of the Cordilleras, which must be crossed by a cut about 110 meters deep (361 feet) if a sea-level canal is contemplated, or by a very considerable cut, but little less than 70 meters deep (230 feet), if a canal with locks is intended. On the other hand, there is the river Chagres, a torrential stream, subject to sudden freshets, of which the canal must necessarily follow the valley for a great portion of its length and against which it must be protected by a proper regulation of the flow in order to insure the safety of navigation.

A third difficulty of a general nature presents itself when a canal with locks is considered; the question of water supply assumes, on account of the extent of the several needs to be provided for, an importance suggested by the fact that the accumulated flow of the Chagres itself and of the other streams on the line of the canal becomes insufficient during a certain portion of the year.

The first two difficulties increase as a lower and lower level of the canal is sought, and acquire their maximum of intensity in the case of a canal without locks.

On the contrary, the third difficulty, which appears only with a canal with locks, becomes greater as the summit level is raised.

The first difficulty, relative to the excavation of the great cut at the summit separating the two watersheds, does not raise any special technical question; it is simply the work to be done by manual labor, which may require more or less time and expenditure, but which, being without any inherent element of impossibility on account of the well-known character of the material, does not require any special study. It is the practical problem of a large excavation to be made within a restricted space.

PRINCIPAL DIFFICULTY ENCOUNTERED BY A CANAL WITHOUT LOCKS.

The second difficulty, due to the presence of the river Chagres upon the same territory as the canal, is, in view of possible consequences, of a more serious order. The rectification of the bed of the river for the purpose of utilizing it for the canal can not be contemplated. The irregularity of the flow and the violence of the large freshets are incompatible with a solution of that kind. To turn the stream completely from its course and to direct it to the Pacific slope, far from the location selected for the canal, an idea formerly advanced and in part considered, would be a colossal undertaking, requiring an amount of labor which would render it impracticable. It is a solution upon which it does not seem possible to dwell. It therefore becomes necessary to make of the river and of the canal two neighbors, whose character and wants are to be harmonized. This is a solution which seems very difficult when considering a canal without locks. In fact, from whatever point of view it is considered we must acknowledge that it is necessary to prepare parallel to the canal an artificial waterway capable of discharging under occasional flood conditions a very large flow per second, and this even when the waters of a large portion of the watershed have been temporarily stored in a reservoir to be provided.

An artificial bed established at a higher elevation than the canal itself would prove to be not only a work very difficult to execute, but also to be a danger, a permanent menace, to the canal itself.

We can consequently state that the principal obstacle to the execution of a canal without locks results less from the difficulties entailed by the execution of the deep cut at the summit than from those which spring from the proximity of the Chagres in the region to be crossed before reaching that summit. It will not, perhaps, be too much to maintain that herein lies an obstacle insurmountable to a conception of that kind.

^a The commission of engineers mourns the loss of Mr. Sosa, drowned in the sinking of *La Bourgoyna*.

RAPID GLANCE AT THE PLANS OF THE OLD COMPANY.

It is, nevertheless, this plan which the old company adopted and tried to carry into effect almost to the last days of its existence, under the dominating pressure, we may say, of the man who ruled its destinies. All know to what degree this influence determined the plans. The great cut at the summit was, so to speak, only attempted. Out of a depth of 110 meters (361 feet) on the center line at the culminating point of the crest only 20 meters (66 feet) were excavated. As to the question of the regulation of the Chagres, we may remark that if the old company perceived and weighed the difficulties, they had reached no real solution of them. The dam they had proposed at the much-discussed location of Gamboa, to store up temporarily a portion of the Chagres freshets, was never begun. As to the derivation channels provided below alongside the canal to carry whatever water the reservoir could not hold back, we have good reason to state that these channels were far from answering their purpose. In fact, this important question remained yet to be solved when the irresistible pressure of events obliged the company to modify their plans and abandon, as they supposed provisionally, a canal without locks and substitute for it a canal with locks.

To the two great difficulties encountered in building a canal without locks was thus added a third, relating to the water supply of a canal with locks.

Circumstances allowed the company no time for long reflection or for varied and protracted study of the problem under the new conditions. They were forced, as it were, without delay to improvise and execute.

Concerning the execution of the large cut, the company took measures which were evidently the wisest under the circumstances, viz, reducing it to a minimum by establishing the summit level as high as possible, but with limits a priori acceptable; they fixed the elevation of its bottom at 40 meters (131 feet) above mean sea level, which change would diminish by 50 meters (164 feet) the depth of the cut required for a canal without locks.

They proposed five single locks on each slope, each 18 meters wide (59 feet) and having a serviceable length of 180 meters (591 feet) with a lift of 11 meters (36 feet).

The water-supply question was solved in a manner suggested by the idea that such a canal with locks was only a temporary expedient. It was to be accomplished by machinery pumping water from a reservoir to be formed by the building of the Gamboa Dam, raised to a height much less than in the case of a canal without locks.

As to the question of the disposition of the Chagres, it is likely that a study of its complete solution had been postponed.

It would be out of place to criticise here the plans for a canal with locks as proposed by the old company, but of which the execution under the pressure of events was merely begun. The preceding brief sketch concerning past facts has no other object than to emphasize the point that the conception of the old company furnished no solution in any way satisfactory to the three fundamental questions which arise when the building of a canal with locks across the Isthmus of Panama is considered. We can only learn from the unfortunate past that material proof has been furnished that a canal without locks to unite the two oceans is an undertaking the realization of which can not be thought of, certainly for a long time to come.

PLAN OF THE COMMISSION D'ETUDES.

After the failure of the old company, the receiver, anxious not to forfeit the rights acquired from the concession, and thus to lose the benefits of the great efforts already made and of the important results obtained, conceived the idea of undertaking anew, on a different basis, and of carrying through the interrupted work. He named a commission d'études, under the presidency of Mr. Guillemain, inspector-general des ponts et chaussées, whose mission it was to study the status of the undertaking, and, if possible, to establish the basis for a new plan capable of execution within reasonable limits of time and expense. This commission at the start rejected all idea of a canal without locks, which indeed was impracticable in any event under the conditions they had to consider; condemned the plans of a canal with locks as adopted by the old company, which appeared to them to present capital objections, and formulated the program of a plan established upon an entirely different basis, investigating and discussing, with great ability, the three fundamental questions involved in the construction of a canal with locks across the Isthmus.

The first condition to be met by the commission was to devise a plan that should be feasible within the time limit still left before the forfeiture of the concession—about nine years, of which one year would be consumed in resuming the work. The commission accepted, in principle, that the work requiring the longest time would be the excavation of the cut at the central mass at the Culebra, and that this determined the limit of time required for the completion of the canal.

The answer to the first of the three main questions was thus reduced to the more precise and limited form—What depth can we hope to reach at the Culebra Cut in the eighth year of actual work? The answer would furnish an inferior limit for the excavation, below which, everything considered, they could not think of going; that limit they thought should be established at elevation 25.5 meters (84 feet) above mean tide. On the other hand, the solution they thought most satisfactory for the problem of water supply of the canal allowed them to fix definitely the proper elevation for the summit level.

They rejected the suggestion of mechanical supply, which involved too much uncertainty and lacked elasticity to meet the complicated and variable needs of a great maritime canal. They likewise rejected a priori the supply through a feeder that would have to be built in the upper valley of the Chagres, a region, as they said, "practically unknown and crossed by numerous profoundly engorged streams."

The only means left, therefore, was the direct supply by the Chagres itself, whose level would be raised to the requisite height by a dam to be built across its bed at one end of the summit level. They condemned the location of the Gamboa Dam adopted by the old company, which appeared to them to be "one of the least favorable that could have been selected," and recommended a location at San Pablo, P. K. 38 of the canal line. At that point they would close the Chagres bed, and a secondary depression there found, by a dam, which, with two locks, would determine a large lake of which the summit level of the canal would form an integral part; that summit level on the Pacific side would end at Paraiso, P. K. 57 of the canal, with a flight of two locks, and an adjacent dam closing the Rio Grande Valley.

The location which they recommended for the large dam at San Pablo did not, however, leave them without doubts as to the security of this dam. They indicated it only with reserve, stating that in any event it was necessary to use prudence in establishing the height of a dam so directly related to the height of the summit level, since that height would determine that of the lake to be formed. These conservative considerations led them finally to adopt the definite elevation of 25.5 meters above mean sea level (84 feet) as the extreme limit of excavation admitted by the time demanded for the completion of the canal. Thus were studied and solved together the two important questions of the depth of the central cut and of the water supply of the canal.

The third question, probably the most difficult one, that of controlling the freshets of the Chagres, was, in the opinion of the commission d'études, largely solved at the same time. The lake formed by the San Pablo dam became, in fact, a regulating reservoir in which the Chagres freshets could spread out and lose the greater part of their velocity and be, in a measure, temporarily retained, sufficiently to limit the overflow in the lower levels at each end of the summit division.

Allowing a rise of 2 meters (6.6 feet) in the San Pablo Lake, the commission d'études believed they could store 60,000,000 cubic meters (2,119,000,000 cubic feet) at the time of the greatest freshet, allowing to pass through the summit level a maximum flow of only 1,200 cubic meters (42,380 cubic feet) per second, of which 900 cubic meters (31,780 cubic feet) would flow toward the Atlantic and 300 cubic meters (10,600 cubic feet) toward the Pacific. In order to allow the escape of 900 cubic meters (31,780 cubic feet) per second on the Atlantic side without endangering either the canal itself or the navigation, the commission d'études indicated below the San Pablo Lake the possibility of a second lake, formed by building across the Chagres Valley, at Bohio, a second dam with a flight of two locks. This lake would constitute a second level on the canal on the Atlantic side, but was not intended as a storage reservoir. The waters escaping from San Pablo would flow to the sea through artificial channels as located by the old company on each side of the canal, completed as intended, or through the canal itself.

PRINCIPAL OBJECTIONS TO THIS PLAN.

On technical grounds the plan of the commission d'études gives rise to serious objections, as will be indicated further on, but it has the merit of establishing two very rational principles for the solution of the two more important questions raised by the construction of a canal with locks.

The first principle, relating to the depth of the great cut, is that there is no reason to fear that the geological conditions will compel the adoption of too high an elevation, but that it is possible, without running any risk, to adopt a much lower elevation within limits in accord with the time allowed for the excavation.

The second principle is that the solution of the problem of controlling the Chagres River must be looked for in the establishment of reservoirs or artificial lakes outside or on the line of the canal—lakes in which a portion of the freshets will be temporarily retained while the remainder would flow to the sea without causing danger or even delays to navigation.

In fact, these two principles should dominate all subsequent plans, being, however, so applied as to eliminate from that of the commission d'études certain objectionable features which are mainly the following:

In the plan just briefly analyzed, the two questions of the lowering of the cut and of the water supply are closely connected in such a manner that what favors the solution of one is harmful to the other. It is, in fact, necessary to deepen the cut as much as possible, thus increasing the difficulties of the work, in order to facilitate as much as possible the construction of the provisions for water supply, and vice versa. This results from excluding, at the outset, a mode of water supply based upon the construction of a reservoir in the higher valley of the Chagres, and of a feeder for delivering the water to the canal—a method which would prove elastic, so far as the elevation of the summit level is concerned. This first objection is a serious one.

A second objection, still more serious, is raised by the selection of the location of the dam, which is to be the key to the solution, a location concerning which the commission suggested doubt, stating that new surveys were necessary to finally ascertain the character of the foundation. These new surveys have shown that at that point the conditions for building a large dam are very unfavorable, and that no satisfactory location can be found along the canal from the point where the Chagres first meets it (P. K. 45) to Bohio (P. K. 24). The plan of the commission d'études, by this fact, becomes impossible of execution, or only to be prosecuted under doubtful conditions, which they themselves declare would constitute a capital defect. Even were this dam feasible, a very grave objection could still be raised concerning the disposal of the Chagres freshets.

The impounding of 60,000,000 cubic meters (2,119,000,000 cubic feet) of water, estimated as the excess of the river freshets over a volume of 1,200 cubic meters per second (42,380 cubic feet) passing the dam, is altogether insufficient. The thorough study made of the floods of the Chagres by means of numerous observations leads to the conclusion that the real excess to be impounded over an allowable maximum flow of 1,200 cubic meters (42,380

cubic feet) through the channel would reach 250,000,000 cubic meters (8,829,000,000 cubic feet). Thus we see how inadequate would be the reservoir provided by the commission d'études.

They suggest, it is true, that if their estimate of this volume is too small it would only be necessary to allow the excess of water to escape on the Atlantic side, even interrupting navigation temporarily, if necessary. But this would simply be an expedient which, under certain possible conditions, might prove disastrous to the canal and harmful to navigation.

These several objections constitute, from a professional point of view, reasons of sufficient importance to warrant the rejection of the plan of the commission d'études.

That commission allowed a period of eight years of effective work. They established in a general way the principle that the excavation of the central cut, everything being considered, is the work requiring the longest delay, and fixing the measure of time necessary for the completion of the canal.

This opinion may be erroneous, and we are led to believe that it is so, even with the plans of the commission d'études. The aggregate of the masonry work required for a canal with locks may demand a longer time than the excavation of the central cut, if the latter be reduced to relatively moderate proportions. In the especial case of the plan of the commission d'études we think that the complicated group of structures which closes the valley at San Pablo (locks, dams, overflow weirs, etc.), together with the change of location of the Panama Railroad, which must precede them at least in part, would require a longer time than eight years. This, however, is but a secondary objection, because even the foundations of the plan do not appear to be admissible.

We must, however, retain from the labors of the commission d'études the fundamental principles on which were based their plans—principles altogether rational, notably in what concerns the control of the freshets of the Chagres. These principles, if broadly applied, with the advantage of more precise data and more thorough surveys than the commission had time to make, will furnish a satisfactory solution of the complicated problem before us to-day.

PLAN OF THE NEW COMPANY.

The plans of the commission d'études were never carried into effect. At the request of the receiver the Government of the Republic of Colombia agreed to a prolongation of time granted by the concession for the completion of the canal.

A new company, completely independent of the old one, was formed with a view to study a practical basis for the completion of the canal, to the benefit of all the interests involved, and to effectively prosecute the same.

POLICY ADOPTED BY THE NEW COMPANY.

Actuated by the spirit of its by-laws, the new company at the outset adopted as a program, and took as a guiding principle, the examination and study of all questions which could be raised in the minds of practical and professional men, in order to be enabled to discuss and prepare with perfect knowledge the advantages and difficulties of the undertaking.

The technical commission could not but fully approve this method, which, judiciously applied, required complete and accurate knowledge of the topographical and geological formation of the region where it is proposed to make the canal, as well as all the special peculiarities and local conditions which have a bearing on the methods of execution; in short, of all the data relating to the details which are involved in a study of the plan.

The new company also resolved, in order to justly estimate the material difficulties offered by the excavation of the deep cut, and in order to settle, by actual facts, the uncertainties which had existed in all discussions on that point, to actually dig a central trench to such a depth as would leave nothing hypothetical as to the character of the final work. The excavations so made entailed no ultimate loss, as they became an integral part of the final cut.

The fulfillment of this preliminary program demanded several years, but the time thus devoted to investigation and experiment has been far from wasted. It is an axiom applicable to public works of magnitude that the more the surveys and the preparation of the plans are elaborated and carefully studied the more the execution is rapid and sure. We may properly add that the execution of great public works too hurriedly started, without sufficient discussion to allow of definitely determining what is intended to be done and what can be done, leads to great disappointment and delay, even when it does not end in disastrous failure, as was the case with the old company. We may even affirm that the primary and principal cause of the nonsuccess and failure of that company was the lack of the necessary preliminary study.

PRINCIPLES APPLIED TO THE STUDIES OF THE SEVERAL PLANS.

Simultaneously with the progress of the surveys, and with that of the excavation carried on at the Culebra to furnish material data as to the formation of the central mass, the stability of the material there encountered, and the difficulty of its removal at increasing depths, the engineers of the company, constantly advised by the technical commission, prepared several plans for a canal with locks, based on different assumed elevations of the bottom of the summit level. Thus a great variety of combination was studied successively in detail.

The technical commission has uniformly adopted as principles from which no deviation was allowed in the several studies and which restricted their scope: (1) Every solution must be rejected a priori which, in itself, and apart from any consideration of time and expense, does not present absolute guaranty of certain success; (2) in preparing the plans of the several structures required by so important and complicated a work, such types only should

be adopted as have been proved to be satisfactory by experience, barring out all innovations which might lead to failure; (3) in the examination of all questions, the special conditions under which the work is to be executed should be taken into account, as well as the characteristics of the climate, the influence of which may show itself in the inferior quality of labor and in the reduced efficiency of the personnel which directs it. Hence the necessity to plan only simple structures requiring no special conditions in the means of execution.

In every study are found, as principal questions to solve, the three fundamental problems which arose in all plans prepared previous to those of the new company, viz, possible depth of the central cut; mode of water supply; mode of controlling the Chagres freshets.

POSSIBLE DEPTH OF THE CENTRAL CUT.

The question of the possible depth of the central cut, especially in that portion of the main divide formed by the Culebra, depends on two elements:

- (1) The nature of the material to be excavated, which determines the conditions of stability at various depths.
- (2) The material difficulties attending the excavation, upon which depend the necessary time and expense.

At first the company, somewhat influenced by inherited fear of the unstable formation to be encountered, and following the prudent principles they had adopted, thought it necessary to reduce the depth of the cut to a minimum compatible with the execution of a canal offering sufficient facilities to navigation.

A tentative plan, elaborated accordingly, placed the canal bottom at the summit level at 34 meters (111.6 feet) above mean tide; that plan required five locks of a maximum lift of 10 meters (32.8 feet) on each slope. But experience at the excavation carried on in the deep cut has shown that the chances of instability are limited to the upper strata, which must be passed through under all plans, and these fears have been now allayed by the actual progress of the work.

The opening, on a large scale, of the trial trench, and the sinking of many open shafts below the actual cut, some even going to elevation 10 meters (32.8 feet), have given the assurance that the formation below the clayey beds of the upper region present every guaranty of stability, even for steep slopes, down to all possible depths to be considered. The technical commission, several members of which went to the isthmus to see things for themselves, thus became convinced that the formation is not to be considered as an element of limitation with regard to the depth to be assumed for the central trench, and that this point should be determined by considering the time and expense required to reach such or such a depth.

Thus, basing their belief upon actual experience, the technical commission has formulated the principle that the central trench, considered in itself, and solely in the light of the nature of the formation to be encountered, could be made as deep as desired within the limitations necessarily imposed by the possible solution of the other questions, and also by the question of the time to be allowed for completion.

MODE OF SUPPLYING WATER TO THE CANAL.

The question of water supply for the canal has given rise to the most varied and complete studies. The technical commission decided that they could not admit the principle of a mechanical supply as a final solution. Whatever precautions might be taken, such a solution, independently of the great permanent expense entailed, would be too precarious to be admitted for the operation of a canal of such a magnitude. Hence only two solutions were left as possible—either direct supply by the Chagres, transformed into a lake, which itself would constitute the summit level of the canal (this arrangement had been adopted by the commission of 1890), or supply through a feeder from a point in the upper valley where a reservoir could be formed by the building of a dam the flow line of which should be so calculated as to carry the water supply to the summit level at the proper elevation.

DIRECT FEEDING BY THE CHAGRES.

Concerning the first of these methods, it was ascertained by local examinations and investigations that the solution pointed out by the commission d'études could not be applied; that in the whole of the Lower Chagres Valley—between Gamboa and the sea—only one location showed favorable conditions for the building of a high dam capable of impounding a lake which could become the summit level.

That location is that of Bohio Soldado (P. K. 24 of the canal line), where the above-named commission had located a secondary reservoir to form the second level of the canal in their plan. The character of the formation at that point in the thalweg of the Chagres allows the building of an earth dam of a certain height; but, after carefully studying the geological formation of the underground strata which was clearly revealed by numerous test pits, the technical commission unanimously agreed that it would not be prudent to build on that location a dam forming a reservoir of a depth of more than 20 meters (65.6 feet) above the river bed, which at that point is at about the mean level of the sea.

Considering the importance of that structure in relation to the safety of the canal itself, it was deemed that here, more than anywhere else, it was necessary to be very cautious, and consequently the maximum elevation of 20 meters (65.6 feet) was fixed upon as that of the level of the lake to be formed by the building of the Bohio dam.

Under these conditions, if it is desirable to adopt the Chagres itself as a feeder by utilizing the central lake formed as above stated as the summit level of the canal, the maximum elevation of that level must be 20 meters (65.6 feet) or thereabouts. From this it follows that with a minimum depth of 9 meters (29.5 feet) in the canal, and

allowing for a certain variation in its level, due to the variable supply it may receive, the bottom of the summit level, of which the deep cut would be a part, must be established in the neighborhood of elevation 10 (32.8 feet).

Such is the result to which we are led in considering direct feeding through the Chagres if we do not wish, in determining the proportions to be given to the main structure of that plan, to deviate from the prudent rules which the commission consider as absolute.

The great depth resulting therefrom for the central cut does not seem incompatible with the conditions of stability upon which we may rightly depend, knowing as we do the formation to be encountered; but to-day it does not seem likely that we can execute the work within the time that we shall have to establish.

FEEDING THROUGH A DERIVATION CHANNEL FROM THE CHAGRES.

If we reject direct feeding, as explained above, we can only supply the canal by means of a reservoir to be formed by a dam in the upper valley and of a new channel connecting that reservoir with the summit level.

On that subject two plans were carefully examined, both based upon the results furnished by the surveys made in all the upper watershed of the Chagres, and upon the study of the country made by several members of the technical commission.

In one plan the solution would be based upon the building of a dam at Gamboa, in the immediate vicinity of the summit level of the canal, thus forming a storage reservoir for its supply. We know that the old company, while projecting the building of a dam at that place, had considerable misgivings, and that the commission d'études formally rejected it, saying that "it was one of the most unsatisfactory locations that could be selected." However, on account of the great advantages presented by a Gamboa dam for supplying the canal, it was thought important to study the question upon material data altogether reliable. A complete and very accurate survey of the location was made; numerous test pits were sunk on the probable line of the dam to ascertain the nature of the ground above rock bottom and the nature and exact depths of the latter. Upon these data several plans for a dam were studied, such as would appear most feasible from a technical point of view. As a result of protracted discussions and of a thorough consideration of the modes of construction presented, the commission did not feel assured that there would be in the erection of that structure any sure chance of success and, in the future, those absolute conditions of safety upon which it is imperative that they should rely.

Other grave objections seemed also inseparable from a reservoir of so large proportions located in close proximity to the canal. Consequently, at their meeting of September 6, 1898, the technical commission decided that it was imperative to reject any solution based upon the building of a dam at Gamboa. But contrary to the conclusions of the commission d'études, which, with hardly any data to guide them, had (a priori) rejected the idea of building a dam in the upper Chagres above Gamboa, with a feeder between that dam and the summit level of the canal, the technical commission thought that solution feasible under satisfactory conditions.

They based this conclusion upon most complete investigations carried on in the locality in question, which gave a very good knowledge of all the conditions. At the place commonly called Alhajuela, a very favorable location exists for a high masonry dam, the foundations of which could be established upon a compact rock formation. From complete surveys and from the inspection of the locality made by several members of the commission, it is known that the difficulties of constructing a feeder line between that dam and the summit level of the canal are not of a prohibitory nature. By the building of a branch of the Panama Railroad up the valley of the Chagres to Alhajuela, closely skirting the proposed line of the feeder, the whole locality of the works would be as accessible as those portions of the isthmus occupied by the canal itself.

Under these conditions the plan of supplying the canal by building a retaining dam in the upper Chagres and delivering the water through a feeder seemed to the Commission perfectly feasible; therefore they agreed that it would be advisable to build a canal with locks, the supply of which would be furnished by the method just described. The advantage of that solution is the wide limit allowed in the selection of the elevation of the summit level, which may thus be established much higher than that required for a direct supply through the Chagres proper.

REGULATING THE FRESHETS OF THE CHAGRES.

The question of regulating the Chagres freshets, constituting the third element of the general problem of the building of a canal with locks, was studied with care.

It is true that the continued and careful observations made to that end did not extend over such a length of time as would enable us to affirm that they cover the most extreme cases. They go back, however, to the first years of the old company's existence, and we have been able, by studying the numerous data collated by it and preserved in the records turned over to the new company, also by combining notes made at the time of the 1879 freshet, which, from the testimony of witnesses, the marks it left, and the damages it produced, seems to have been the greatest within the memory of man (it is, at all events, the greatest which has occurred since the building of the Panama Railroad in 1850), to form a very well-founded estimate of the extreme conditions to be met in the solving of the problem of the regulation of the freshets of the Chagres. That question has been repeatedly discussed at the meetings of the technical commission and formed the subject of an elaborate report from one member, which is contained in a note accompanying the minutes of the sixty-third meeting. The points given in that report, relating to the maximum output of the largest freshets at important points along the river, have appeared sufficiently comprehensive to warrant the opinion that, by basing on them the solution of the problem, we may rest assured of

having so solved it as to meet the most unfavorable cases. Nevertheless, the general plan adopted is such that, even if the precautions taken to provide for the largest freshets known in fifty years should be insufficient, nothing would be endangered; the only consequences which could result therefrom would be a short interruption to navigation in the Bohio level and perhaps the necessity of suspending it for a brief period in very exceptional circumstances.

The principle followed by the new company, which the technical commission has completely approved, is the one adopted in a general way by the commission d'études, namely, the formation of reservoirs in which the freshets of the Chagres will spread over large areas, and where will be temporarily stored up, in time of flood, the volume of water in excess of the quantities which can be safely allowed to flow through the canal and its appurtenances.

Such is the principle admitted by both commissions as a basis; but the adjustment of the actual plans provides much greater security than that of the commission d'études. In reality that commission had only provided one lake for regulating the freshets, that at San Pablo, including the summit level of the canal and formed by the building of a dam at (P. K. 38) of the canal line. That lake, estimated to cover 3,000 hectares (7,400 acres), was to be of such capacity as to impound in a horizontal space of 2 meters (6.6 feet) a volume of 60,000,000 cubic meters (2,119 million cubic feet) to be retained out of the maximum output of the freshets. As stated above, the new investigations establish that the real volume to be retained at the time of the largest freshets, while allowing a free flow of 1,200 cubic meters (42,380 cubic feet) per second, as had been done by the commission d'études, will probably reach 250,000,000 cubic meters (8,829 million cubic feet). The lake proposed by that commission would therefore be inadequate, and it has been explained elsewhere that the San Pablo dam is not practicable.

The elaborate discussion of the conditions to be fulfilled in order to harmonize the regulation of the Chagres freshets with the exigencies of water supply for the canal has established the necessity of making provision for two large reservoirs or artificial lakes. The first one, comprising the central region of the canal and containing one of the levels thereof, would be formed by the building of the Bohio dam (P. K. 24), and would have a maximum flood height fixed at elevation 20 (65.6 feet) or thereabouts. It would cover an area of 5,500 hectares (13,600 acres), and be able to impound, between elevations 17 meters (55.8 feet) and 20 meters (65.6 feet), a reserve of about 150,000,000 cubic meters (5,297 million cubic feet). This storage capacity would be reduced to about 100,000,000 cubic meters (3,532 million cubic feet) by a fluctuation of only 1.75 meters (5.7 feet).

The second lake would be formed in the upper Chagres Valley by the building of a dam at Alhajuela. That dam would form the source of supply of the feeder in case it is decided to build the latter.

At the height adopted for this dam a lake would be formed on the upper river which, at the mean elevation of the storage reserve of the freshets, would cover an area of about 2,600 hectares (6,425 acres), and would allow the impounding, with a change of level of about 4 meters (13.1 feet), of 100,000,000 cubic meters (3,532 million cubic feet), thus completing, with the reserve in the Lake Bohio, the 250,000,000 cubic meters (8,829 million cubic feet) which should be held back during the greatest freshets.

Even in the event of the great cut at the summit being lowered sufficiently to reduce the summit level of the canal to that of Lake Bohio (the bottom of the canal being then at elevation 10), (32.8 feet) Alhajuela Lake should not be dispensed with. Its sole use would then be to constitute a large reservoir in which would be stored the volume of water necessary for the water supply and the operation of the canal during the periods of deficiency in the natural output of the Chagres and of that portion of the excess of the freshets which must be retained in order to restrict the oscillation of Bohio Lake to its strictly necessary limit and thus avoid too great fluctuations of its surface. In that case the maximum of reserve to be allotted to the Bohio Lake would be reduced to 100,000,000 cubic meters (3,532 million cubic feet), and that allotted the Alhajuela Lake would be raised to 150,000,000 cubic meters (5,297 million cubic feet). The height of the dam at Alhajuela would not be altered, but the outlet would be lowered, which would become practicable because there would then be no feeder to supply, the delivery being by the natural bed of the river.

The technical consideration forming the basis of the general solutions just indicated can be summed up as follows: The greatest known freshet may be assumed as having produced at Bohio, at the time of its maximum, a discharge of about 3,000 cubic meters (106,000 cubic feet) per second. It is admitted that it is safe to allow the escape, through the overflow weirs of the Bohio reservoir, to the right and to the left of the canal, a total volume of 1,200 cubic meters (42,380 cubic feet) per second.

The estimates that may be made of the régime of the freshet under consideration lead us to assume that the time during which the output was greater than 1,200 cubic meters (42,380 cubic feet) was about forty-eight hours, and that the mean output during that time was 2,600 cubic meters (91,800 cubic feet) per second. The volume to be impounded would then be 1,400 cubic meters (49,400 cubic feet) per second during forty-eight hours, or 242,000,000 cubic meters (8,546 million cubic feet); say 250,000,000 cubic meters (8,829 million cubic feet). A flood of that magnitude at Bohio can take place only in the event of the determining climatic conditions acting with intensity over the entire watershed, and we can estimate, from a study of the data at hand, that in that case 52 per cent of the total output admitted at Bohio would come from the portion of the watershed above Alhajuela; this gives for the considered period of forty-eight hours an output of 234,000,000 cubic meters (8,264 million cubic feet) coming from the upper region. It will then be always possible to retain in the Alhajuela reservoir 100,000,000 cubic meters (3,532 million cubic feet) or 150,000,000 cubic meters (5,297 million cubic feet), in accordance with whichever of the above plans is adopted. The regulation of the Chagres freshets is therefore absolutely insured by the arrangements just described.

If, contrary to expectations, a freshet should exceed the proportions upon which the preceding calculations are based, the level of Lake Bohio could be allowed to rise above the established limit; by these means its storage capacity would be increased and the flow over the spillways of the lake would be carried above 1,200 cubic meters (42,380 cubic feet) per second. The plans are so adjusted that no damage would be caused to the canal thereby.

The advisability of building the Alhajuela dam with its storage reserve, even in the case that a feeder should become unnecessary (on account of Lake Bohio forming the summit level), results from two main considerations: First. The abandonment of Lake Alhajuela would lead to the concentration of all the surplus flood waters in the Bohio Lake, which would be possible only by giving the dam an increase of several meters more in height, a scheme unanimously looked upon as overbold, or by lowering the minimum level of the lake as well as that of the bottom of the central cut by several meters, which is not admissible. Second. The abandonment of the upper lake, which constitutes the first regulator of the Chagres floods, would allow that river to enter furiously that portion of the canal territory occupied by the Bohio Lake, where are found, for several kilometers near the point of ingress, bends and natural narrows where the total volume of the freshets would certainly produce currents detrimental and dangerous to navigation. It is true that resource could be had to a suspension of navigation at critical times, but it would be a regrettable alternative of a nature to throw a certain amount of discredit upon the efficiency of the canal; it is certainly preferable to avoid this objection by a relatively small additional outlay. Moreover, it is important to notice that the building of this dam will provide a considerable motive power which will be advantageously applied in the working of the canal itself. The expense incurred would thus be plainly justified by the financial return to be obtained therefrom.

In fine, the solution considered by the technical commission as perfectly judicious and efficacious for regulating the floods of the Chagres consists in the formation of two lakes—one in the upper valley, by the building of a masonry dam (cement concrete) at Alhajuela; the other in the lower valley, about the central region of the canal, by the building of an earth dam at Bohio. This second lake will form one of the levels of the canal; and, according as this level should be the summit level or simply an intermediary one, the water supply would be provided either directly through the Chagres itself or indirectly from the Chagres through a feeder connecting the upper dam with the canal.

VARIOUS PLANS CONSIDERED—TWO GENERAL TYPES.

The general principles which must serve as a basis for the solution of the three fundamental questions before mentioned, arising in the consideration of a canal with locks, being thus defined and established, there remains to be considered how they can be applied and which plan appears to be preferable.

We shall, consequently, indicate the various technical considerations which it has been deemed useful to study in view of the ultimate formulation of a plan for a canal with locks; such combinations will be found to differ from each other only as to special and less important details, which remain to be decided, and which, compared with those already presented, can be qualified as secondary.

The various plans studied can be classified under two general types; one in which the summit level of the canal has a higher elevation than Lake Bohio (a lake which is necessarily a part of all solutions), and in which the supply of the canal is accomplished by means of a feeder starting from the reservoir of the upper Chagres; the other one, in which the summit level of the canal is part and parcel of Lake Bohio, and in which the supply of the canal is accomplished by the Chagres itself emptying into this lake.

SOLUTION OF THE FIRST TYPE.

In the first type a number of combinations can be considered, varying in accordance with the elevation assigned to the summit level. We shall be restricted in that research by the number of locks to be established on each slope and by the maximum lift to be allowed for these locks. We at first admitted that five locks on each slope was a maximum not to be exceeded. As to the lift to be adopted, we decided that we would reject the argument founded on the advantage of using material purchased by the old company for locks of 11 meters (36.1 feet) lift. These materials, which were intended for much narrower locks than is now considered necessary, would not easily meet the new conditions. Therefore no weight should be given to that argument, and the question should be examined without reference to the past.

It is advantageous to reduce the lift of the locks as much as possible. The building of the gates and their operation afterwards will be easier if they are of a less height; the probabilities of damage or imperfect maneuvering are also decreased. The consumption of water in the locks is reduced in the same proportion as the height of the lift, and this is an important consideration when we realize that the supply from the Chagres itself is inadequate during a certain season of the year, and that it will be necessary to establish reservoirs to be drawn from during that period. Again, the time necessary for filling and emptying the locks and for operating them increases with the height of the lift; hence, the time of passage increases with the lift, and the commercial usefulness of the canal decreases proportionately.

All these considerations have led the technical commission to decide that it would not be advisable to go beyond a 10-meter (32.8 feet) lift, and that even a reduction to 9 meters (29.5 feet) would be very desirable if the consequent deepening of the central cut does not give rise to serious objections.

The first plan studied included five locks of 10 meters (32.8 feet) lift; the result was the assumption of elevation 34 meters (111.6 feet) as that of the bottom of the summit level, with an excavation of 12,000,000 cubic meters (15,696,000 cubic yards) in the large central cut comprising the Emperador and the Culebra. The experience

acquired in the course of the present work of excavation in the central trench convinced us that we could, without fear of danger from the nature of the formation, excavate below that elevation without exceeding the time required for the other parts of the work.

At their meeting of May 20, 1897, the technical commission agreed under any circumstances to establish at elevation 30 meters (98.4 feet) or thereabouts the maximum height for the canal bottom in the summit level. Under these conditions it was possible, by retaining five locks on each slope, to reduce the lift to 9 meters (29.5 feet). A second plan was studied upon these bases giving an elevation of the canal bottom in the summit level of 29.50 meters (96.8 feet) and its maximum water surface at an elevation of 40 meters (131.2 feet). The total excavation required by that plan at the central cut would be about 15,500,000 cubic meters (20,274,000 cubic yards).

At the same time, and in accordance with the decision to limit to a maximum elevation of 30 meters (98.4 feet) the bottom of the summit level, we examined a modification of the primitive plan, with 5 locks of 10 meters (32.8 feet) lift, by suppressing a lock and lowering the bottom of the summit level from elevation 34 meters (111.6 feet) to elevation 25 meters (82 feet)—the total excavation of the central cut being 20,000,000 cubic meters (26,160,000 cubic yards). The study of that variant, made as thoroughly as the one in which the elevation is 29.50 meters (96.8 feet), led to the discovery that it would not be economical, but, on the contrary, would entail a greater expense, while the reduction of 4.50 meters (14.8 feet) in the elevation of the summit level would offer but little advantage. The number of locks on each slope would be reduced from 5 to 4, it is true, but the lift would be raised from 9 meters (29.5 feet) to 10 meters (32.8 feet), with all the consequent disadvantages enumerated above for the working of the canal and for navigation. Owing to these considerations this arrangement was not deemed judicious, and was not found to offer real advantages over the former plan with 5 locks of 9 meters (29.5 feet) lift. On the whole, the plan at elevation 25 meters (82 feet) constitutes an intermediary system, a sort of hybrid, between that of 5 locks with 9 meters (29.5 feet) lift and the one naturally derived from it by the suppression of one step. The technical commission decided, consequently, that it should be excluded from the number of solutions useful to discuss.

On the other hand, actual work in the central trench proving to be more and more reassuring and to warrant the belief that it would be possible, without misgivings as to the stability of the formation, to deepen the excavation much below elevation 30 meters (98.4 feet) already established as a maximum, we thought it very interesting and useful to examine a variant directly derived from the plan with five locks and 9 meters (29.5 feet) lift by simply suppressing the upper step. Thus is reached a system of four locks with 9 meters (29.5 feet) lift, in which the bottom of the summit level is lowered to elevation 20.75 meters (68.1 feet) with a surface elevation of 31.25 meters (102.5 feet). This solution demands the excavation of 24,000,000 cubic meters (31,392,000 cubic yards) in the central cut, instead of the 15,500,000 cubic meters (20,270,000 cubic yards) in the five-lock solution. As to the total cost of the work, the two systems practically balance each other, the increase due to excavation being nearly compensated by the economy realized upon the rest of the work. Therefore, the only question which presents itself in the comparison to be made of the two systems aside from the manifest advantage that the second presents over the first in a general way, arises from the time necessary to complete them. The answer to this question will furnish us with a decisive reason for a choice to be made between the two. It should be noted here that the study of the second was made in such a way as to conform to the first in all respects, except as regards the works of the summit level, which are altered by the fact of an additional deepening of 8.75 meters (28.7 feet). Hence most of the work could be executed equally for either plan.

Another variant of the same general plan was studied, consisting in the suppression of a second step of locks, thus reducing their number to three on each slope; but this study is only speculatively interesting. It leads to a lowering of the summit level to nearly the same point as is contemplated for the second type, where the water supply is provided directly by the Chagres, a doubtless preferable arrangement. There is, then, no reason to further dwell on this modification.

In fine, for the reasons just given we were induced to retain two solutions only from those relating to the first type—namely, one with five locks with 9 meters (29.5 feet) lift, requiring elevation 29.50 meters (96.8 feet) for the bottom of the summit level; the other with four locks of 9 meters (29.5 feet) lift, requiring elevation 20.75 meters (68.1 feet) for the bottom of the summit level.

SOLUTIONS OF THE SECOND TYPE.

The solutions considered under the second type, in which the summit level is a part of Lake Bohio traversed by the Chagres, are reducible to two.

In the one a single lake only is to be built—Lake Bohio—and it must provide for all necessities—the water supply and operation of the canal and the regulation of the freshets of the Chagres. In this system, the bottom of the summit level being established at elevation 10 meters (32.8 feet), the maximum level of its water surface, which would be also that of the lake, could reach elevation 24.50 meters (80.4 feet) in the large freshets, and the Bohio dam should be raised to elevation 27.50 meters (90.2 feet), which would be about 30 meters (98.4 feet) above its foundations. In the other a first lake would be formed on the upper Chagres by the Alhajuela dam; the function of this lake would be to store up all water needed for supplying and operating the canal, as well as a great portion (the largest) of the excess of the freshets. In that case, the bottom of the summit level remaining practically at the same elevation as before, the maximum level of Lake Bohio would not exceed elevation 20.50 meters (67.3 feet), and the dam would remain very nearly within the limits established for all the plans of the first type. This solution is the only one meeting the conditions for the regulating of the freshets without giving the Bohio dam

such proportions as are considered too bold. On that account principally, and also by reason of the advantages which, in any event, the Alhajuela dam presents by providing a considerable hydraulic power and by permitting a preliminary regulation of the Chagres before entering the canal territory, it has appeared proper to adopt this solution preferably to the first.

SOLUTIONS RESERVED FOR SELECTION.

To sum up, three solutions only are retained for comparison in view of a final choice.

The first two, directly related to one another, comprise a summit level at a higher elevation than Lake Bohio, which is fed from a reservoir to be formed in the upper valley of the Chagres through the feeder.

In the one the bottom of the summit level would be at elevation 29.50 meters (96.8 feet), and there would be five locks on each slope. In the other the bottom of the upper canal level would be at elevation 20.75 meters (68.1 feet), and there would be only four locks on each slope.

In the third solution the summit level is a part of Lake Bohio formed under the same conditions as before, and the canal is supplied directly through the Chagres discharging into the summit level after traversing a reservoir formed by a dam in the higher valley, mainly in view of assisting in the regulation of the freshets, and of taming the river before its arrival in the canal territory. The bottom of the summit level would be closely at elevation 10 meters (32.8 feet).

REASONS FOR THE SOLUTION ADOPTED.

The detailed estimates made for each one of these solutions show that, as regards outlay for actual work, they differ but little from each other. The total expense for the work itself, including large amounts for incidentals, would be:

	Francs.
For the plan at elevation 29.50 meters (96.8 feet).....	490,000,000=\$94,570,000
For the plan at elevation 20.75 meters (68.1 feet).....	512,000,000= 98,816,000
For the plan at elevation 10.00 meters (32.8 feet).....	531,000,000=102,483,000

We know that at the central cut the formation, now well understood, allows the adoption of either of these elevations without fear of serious danger arising from the instability of the ground.

Under these conditions the time necessary to execute one or the other of these three solutions becomes the determining reason of the choice to be made between them. This question has been the object of prolonged discussion among the members of the technical commission—a discussion summed up in the minutes of the ninety-sixth session. It has been recognized, and we can state that it is not possible to formulate a priori a conclusive decision on such a question. So many elements, the value of which it is impossible to calculate with certainty, bear upon the rapidity which may be developed in the execution of the work that we can not establish in advance its exact duration. Nevertheless, especially as regards excavation, we can form a close idea by considering what was formerly accomplished by the old company and by what is performed to-day, applying to such results such corrections as can be rationally deduced from the progress made in methods of work and in organization on a large scale. We can likewise obtain important information from similar great works executed recently, making ample allowance for the differences in climate and in the conditions of labor.

By such means we have formulated estimates as to the time necessary for the excavation, which appear to us to be reasonable.

The problem involved in the cutting of the Culebra itself is obviously of paramount importance. It is undoubtedly the work of excavation which will continue longest, and which, of all operations of that class on the entire canal, will determine the length of time needed.

The amounts to be excavated at that special point, between P. K. 53.600 and P. K. 55.500 in the three plans to be compared, are:

In the plan at elevation 29.50 meters (96.8 feet), about 8,200,000 cubic meters (10,725,600 cubic yards).

In the plan at elevation 20.75 meters (68.1 feet), about 11,200,000 cubic meters (14,649,600 cubic yards).

In the plan at elevation 10.00 meters (32.8 feet), about 15,600,000 cubic meters (20,404,800 cubic yards).

Simultaneously with the excavations the permanent structures must be erected, and it is judicious to establish the principle that, applying to the working of each of these two classes all possible energy, with the means of execution and the labor resources upon which we may reasonably rely, it is desirable that their completion be effected as nearly as possible in about the same time, a condition which would reduce to a minimum the duration of the undertaking. This consideration is, from every point of view, of capital importance, and it constitutes the determining reason for a decision as to the plan to be adopted.

But, among the various works to be completed, there is a complex group, the execution of which can only be accomplished in successive installments, and this will certainly require a longer time than all the others. It is the aggregate of the structures constituting the closing of the valley at Bohio (dams, locks, spillways, etc.).

The study made of the methods to be adopted for the construction of these structures, which is summed up in the minutes of the ninety-fifth session of the technical commission, leads to the conclusion that the total time necessary for the completion of this group of structures will be about ten years. It is not to be doubted that, within the same time, all the other works can be completed, including the change of location of the Panama Railroad and the feeder, if needed.

In fine, then, the question of the time demanded by each of the three plans under consideration is reduced to comparing on one side the group of the Bohio works, which, being the same in the three plans, will require the

same time—about ten years—and, on the other, the work at the Culebra, the excavation of which varies considerably in the three plans; then, to consider in which of them the excavation of that deep cut will require practically the same time as the Bohio works. After thoroughly discussing this question, the technical commission has decided that, according to the actual experimental data, it is the plan at elevation 20.75 meters (68.1 feet) which is the most favorable, in that it offers the most chances of fulfilling the fundamental condition of equilibrium in the time required for the two principal groups of works; consequently, at their meeting of September 8, 1898 (ninety-seventh meeting), they formulated the conclusion of their studies and advised the company to adopt the plan just mentioned, the detailed description of which will be the subject of the following chapter.

It is clear, from this short analysis of all the plans considered and from the discussion arising therefrom, that, under the light of the facts brought out during the experimental work which the new company had decided to have performed before a final decision should be reached, owing also to the data furnished by the surveys made and the test pits sunk on the Isthmus, with a view to study all solutions that could reasonably be thought of, the present plan has been evolved progressively. At the outset there was a preference for the plan of a canal with a high summit level, which was later changed for the more advantageous one of a canal with a much lower summit. This solution, gradually brought about by the procurement of material facts, has resulted from the policy of protracted experimental research and of painstaking study which the new company thought proper to adopt in the beginning; it also constitutes the justification of that policy.

CHAPTER II.—*Description of a plan for a canal with locks, with bottom of summit level established at elevation 20.75 meters (68.1 feet).*

The main questions which will be the subject of this chapter relate to—

First. The plan or location of the canal.

Second. The longitudinal profile showing the various levels.

Third. Standard cross sections adopted for the several levels, widths, and areas of these levels.

Fourth. The general arrangements adopted for the locks.

Fifth. The ports of ingress or waiting basins provided at each end of the canal.

Sixth. The general earthworks of the canal.

Seventh. The various structures.

Eighth. The feeding system and its appurtenances.

Ninth. The Upper Chagres Railroad.

Tenth. The arrangement adopted for the regulation of the freshets, derivations, and widenings.

Eleventh. The change of location of the Panama Railroad.

Twelfth. The general expense of the undertaking.

ARTICLE 1.—*The plan or location of the canal.*

The location adopted for the plan of canal under consideration is precisely the same which was agreed upon and followed by the old company for the scheme of a canal without locks, and later for the scheme of a canal with locks, which they had begun to substitute for the first. That location was judiciously selected, and there was no technical reason to modify it. On the contrary, there was economy in preserving it in order to benefit by the useful work already done over nearly the whole length of it. It was only necessary to make a few local changes in order to replace curves by straight lines at points of the old location where locks are to be located under the present scheme.

The location includes everywhere on the normal course of the canal large radii, of which the minimum is 3,000 meters (9,843 feet), except in that part corresponding to the central cut, where, on account of the more distorted nature of the ground, the radius of a few curves is reduced to 2,500 meters (8,202 feet). At some special points forming waiting basins on the approaches of the locks the radius at the theoretical center line falls to 2,500 meters (8,202 feet) (Bohio locks), and even to 1,900 meters (6,234 feet) (Obispo locks), but there the width of the canal has been largely increased. Extra widening, moreover, will be provided for all the curves in proportion to their radii, according to the best acknowledged rules.

The total length of the canal from its starting point in the bay at Fox River, on the Atlantic, to its terminus in the Bay of Panama, at La Boca, on the Pacific, is 69 kilometers (42.87 miles); but, deep water being met with only in the vicinity of Noas Island, 5,400 meters (3.36 miles) farther than La Boca, a channel must be dug at sea from that point to the meeting of the permanent deep waters, thus increasing the total length of the canal to 74.4 kilometers (46.23 miles), including that channel.

ARTICLE 2.—*Longitudinal profile.*

The bottom of the summit level is established at elevation 20.75 meters (68.1 feet) above mean sea level; the minimum depth adopted being 9 meters (29.5 feet), it follows that the minimum elevation of the water surface in the summit level will be 29.75 meters (97.6 feet). A possible oscillation of 1.5 meters (4.92 feet) is contemplated to provide for the natural inflow outside of the regular supply, and also for the unavoidable variations of the consumption which require a certain reserve supply. The maximum water surface will thus reach a maximum elevation of 31.25 meters (102.5 feet). As there are hardly any tides on the Atlantic side at Colon, we have a total height of 31.25 meters (102.5 feet) to provide for between that ocean and the summit level. To that end, the plan contem-

plates only one intermediary level formed by Lake Bohio, beginning at P. K. 24.5 of the canal, at the Bohio locks, and ending at P. K. 46, at the Obispo locks.

A double step of two locks is provided at Bohio and another at Obispo. The water surface in the intermediary level will fluctuate between minimum elevation 16 (52.5 feet) and maximum elevation 20 (65.6 feet). The bottom of the canal, which will form almost throughout the lake a buoyed channel, will then be established 9 meters (29.5 feet) below elevation 16 (52.5 feet), or at elevation 7 (23 feet). The bottom of the maritime level is at elevation -9 (-29.5 feet). The Pacific Ocean gives rise to tides varying between the extreme elevations -3 (-9.8 feet) and +5 (+16.4 feet). The total height to provide for between the lowest tide and maximum elevation of the summit level is then 34.25 meters (112.4 feet) on that slope. To that end the scheme provides for two intermediary levels, one located between Paraiso (P. K. 57) of the canal where the lock closing the summit level terminates, and Pedro Miguel (P. K. 59), where there is a double step of two locks. The other level is located between the last group of locks and Miraflores (P. K. 61.8), where there is one lock. The surface of the water in those levels can vary 1 meter (3.3 feet) above their minimum elevation. The elevations of the canal bottom are 13.25 (43.5 feet) in the level adjacent to the summit level, -3.75 (-12.3 feet) in the following level, and -12 (-39.4 feet) in the maritime channel.

The double step of two locks at Bohio is intended to cover a total difference of elevation which can vary from elevation 0 to elevation 20 (65.6 feet), with a possible fall of 10 meters (32.8 feet) in each lock; but we must notice, as stated hereafter, that elevation 20 (65.6 feet) in Lake Bohio is an extreme figure which may only be reached during the greatest freshets—that is, on very rare occasions. We can admit that generally the surface of the lake will not rise above mean elevation 18 (59.1 feet), and that, with regard to normal conditions of operation, the Bohio locks are of 9 meters (29.5 feet) lift.

The maximum difference of elevation to be provided for between the Bohio level and the summit level is between 16 (52.5 feet) and 31.25 (102.5 feet), say 15.25 meters (50 feet) with two locks, giving a maximum lift of 7.65 meters (25.1 feet) for each one.

On the Pacific slope the water surface of the level adjacent to the summit level is at minimum elevation 22.25 (73 feet), which gives a maximum fall of 9 meters (29.5 feet) for the Paraiso lock. The surface of the water in the next level is at minimum elevation 5.25 meters (17.2 feet); the maximum elevation of the preceding one being 23.25 (76.3 feet), we have to overcome with two locks a maximum difference of elevation of 18 meters (59.1 feet)—say 9 meters (29.5 feet) with each lock. Finally, the surface in the maritime level varying between -3 (-9.8 feet) and +5 (+16.4 feet), the Miraflores lock which ends it will have to overcome a difference in elevation which may vary between 2.25 (7.4 feet) and 9.25 meters (30.4 feet.)

ARTICLE 3.—Standard cross sections, widths, and areas of the several levels.

The standard cross sections for the several levels, which were finally adopted by the engineering commission at their ninety-third meeting, are shown in the exhibits. Their peculiarities can thus be resumed:

Atlantic channel.—Bottom width, 30 meters (98.4 feet) or 34 meters (111.6 feet), according to its being dug in ordinary earth or in rocky ground, with slopes of 3 to 2 and 2 to 3 for the wetted prism, and berms 3 meters (9.8 feet) to 2.5 meters (8.2 feet) below the water surface. Two waiting stations are provided along this level, the length of which is 23,880 meters (14.84 miles). These waiting stations have a width of 60 meters (196.9 feet) at bottom and a length of 600 meters (1,968.5 feet), not including the approaches leading to the normal parts of the canal.

Bohio level.—This level, forming a channel across Lake Bohio, extends from (P. K. 24.483) to (P. K. 46). Its bottom width in the normal portions is 50 meters (164 feet), with slopes of 3 to 2 in common earth, and 52 meters (170.6 feet), with slopes of 2 to 3 in rocky ground.

Summit level.—This level extends from (P. K. 46.603) to (P. K. 56.306). It includes the deep trench through the mountains dividing the two ocean watersheds. The standard section adopted for its normal portions includes for the wetted prism a bottom width of 36 meters (118.1 feet), slopes of 1 to 2, and berms of from 3 meters (9.8 feet) to 2.5 meters (8.2 feet) below the water surface. Above the wetted prism the cross section includes berms 5 meters (16.4 feet) wide for every 10 meters (32.8 feet) vertical distance, connected by slopes of 2 to 5, except through the clayey layers at the top, where the slopes are 3 to 2.

Level between Paraiso and Pedro Miguel.—This level, next to the summit level, extends from (P. K. 56.643) to (P. K. 59.07). The same standard cross section as that of the Atlantic level has been adopted. The greatest portion of its length, however, will be made up of the waiting stations at the approaches of the locks.

Level between Pedro Miguel and Miraflores.—This level, which extends from (P. K. 59.373) to (P. K. 61.79), shows likewise the same cross section as the Atlantic channel and, like the preceding one, is mostly made up of the waiting stations at the approaches of the locks.

Pacific level.—This level extends from (P. K. 61.453) to (P. K. 74.400), with a bottom width of 30 meters (98.4 feet) and slopes of 5 to 1 from Miraflores to its terminus at La Boca, where a basin of ingress will be established. From there to the end it consists of a sea channel with a bottom width of 50 meters (164 feet) and slopes of 5 to 1.

In all the levels above and below the locks and close to them waiting stations or basins are provided which will also be crossing points for vessels. These basins will have generally a bottom width of 62 meters (203.4 feet) and a clear length of 700 meters (2,296.6 feet). The length of the curves connecting these stations with the normal section being 100 meters (328.1 feet), the basin adjacent to the Obispo locks on the Atlantic side, which is on a curve with a theoretical radius of 1,900 meters (6,233.6 feet), is provided with a bottom width of 85 meters (278.9 feet).

The respective areas of the several intermediary levels are the following at their maximum water elevation:

	Hectares.	Acres.
Bohio level, about.....	5,500	= 13,591.1
Summit level, including a small natural lake toward Obispo.....	160	= 395.4
Level from Paraiso to Pedro Miguel.....	16	= 39.5
Level from Pedro Miguel to Miraflores.....	13	= 32.1

The area of 160 hectares (395.4 acres), which the summit level covers, with the additional 1.5 meters (4.9 feet) of water above its minimum elevation, constitutes a reserve supply of 2,400,000 cubic meters (85,000,000 cubic feet). This reserve may seem inadequate to amply meet the fluctuations of supply and consumption. It will then be proper to increase it by the formation of a little lake near Paraiso, which can be formed by building a dam across the valley of the Conga and the Mallejon. An additional area of about 100 hectares (247.1 acres) would thus be provided, which would bring the total reserve up to 3,900,000 cubic meters (138,000,000 cubic feet). It could still be made larger by increasing to 2 meters (6.6 feet) the total oscillation of the water level.

ARTICLE 4.—*General arrangement adopted for the locks.*

The general conditions required for the locks have been the object of lengthy discussion, as a result of which the following dispositions have been adopted at the ninety-fourth meeting of the engineering commission:

The locks are to be twin locks, of a useful length of 225 meters (738.2 feet) and a width of 25 meters (82 feet) in the one and 18 meters (59.1 feet) in the other. However, the engineering commission, like the company, believe that for good reasons both are likely to be built with a width of 25 meters (82 feet). One of the twin locks (the narrower one) would be provided with intermediary gates.

The building of one of the twin locks could be postponed (without great inconvenience) until after the opening of the canal to navigation, if the company should find a real financial advantage in that policy.

The system of gates, as adopted in principle, is that of pivoted single doors. This arrangement could be modified, however, in some cases in accordance with the ideas submitted by special builders, from whom detail plans are to be obtained.

Such are the data upon which the locks have been planned.

There is provided below the minimum elevation of the water a vertical depth over the sill of 9.5 meters (31.2 feet) at the side walls and of 10 meters (32.8 feet) on the axis.

The thickness of the middle wall between the twin locks was determined from the hypothesis that one of the locks might be eventually empty in case of repairs, and it was fixed at 15 meters (49.2 feet) at the narrowest part near the point of attachment of the gates. The filling and emptying of the locks is insured by means of cast-iron pipes, 2.8 meters (9.2 feet) and 2.7 meters (8.9 feet) diameter, located under the floor on each side of the locks, and provided with vertical branches of 0.4 meter (1.3 feet) diameter, 2 meters (6.6 feet) apart. This arrangement allows of a simultaneous supply over the whole surface of the lock. The pipes will be controlled by vertical shafts containing cylindrical valves and connected with the canal. These shafts and the aqueducts through which they are connected with the cast-iron pipes are located in the masonry of the side walls.

The masonry of the locks will generally be made of cement concrete. Only those parts intended for special work will be of cut stone, which will be shipped from Europe all ready to lay. Guard gates are provided on the upstream side of the locks, the object of which is to prevent the accidental emptying of the levels.

Timber guards will also be built at the approaches of the locks, and on a line with their sides, to facilitate the entrance or the exit of the vessels.

The details of this timber work must be especially studied in due time, and so will be those for the gates, machinery, and generally for all mechanical appliances.

These items are mentioned in the present report in a tentative manner, in view especially of estimating their cost.

ARTICLE 5.—*Basins for the ingress and egress of ships at each end of the canal.*

It has been thought proper to limit the design of these basins for the present to what will be absolutely necessary for the first needs of the operation of the canal. It will be time when navigation increases to complete the structures which will constitute fully equipped ports of ingress. There is already in Colon, near the point selected for the origin of the canal, a port provided with basins and wharves in direct communication with the Panama Railroad.

These structures, although on a restricted scale, will be at the beginning of the operation of the canal sufficient for the maneuvers of the vessels before their entry into the canal. As, however, the roadstead is rough when certain winds are prevailing, it is important to provide vessels intending to cross the Isthmus with a safe shelter where they can wait. To that effect at the very end of the canal, in prolongation of the bay of Fox River, a spacious basin is to be built 150 meters (492.1 feet) wide and 1,000 meters (3,280.9 feet) long. Mooring facilities are to be established on the shores, and timber guards are to be erected along portions of that basin to allow of the loading and unloading of vessels.

At the other end of the canal, at La Boca, where it empties into Panama Bay, a large basin is provided with an adjacent wharf connected with one of the terminal stations of the Panama Railroad. This port might be gradually improved later on. These works have been executed by the Panama Railroad Company, which thought that a great advantage could be derived for commercial intercourse from thus coming early in contact with navigation,

whereas formerly, on account of the impossibility of reaching the port of Panama, vessels of too large a draft had to discharge their cargoes at a point opposite Naos Islands at a great cost for lighterage.

The maritime channel between these islands and the port of La Boca has only been dug to a depth of 9 meters (29.5 feet) below mean water for the present; it will have to be deepened 3 meters (9.8 feet) when the canal is completed.

ARTICLE 6.—*General earthworks of the canal.*

The excavations necessary to complete the canal under the conditions of the adopted plans are divided as follows in the several levels:

Maritime Atlantic level.—We have indicated in article 3 the standard cross-section which was adopted for this level; it required a width of 30 (98.4 feet) or 34 (111.6 feet) meters, according as it was to be dug in ordinary or in rocky ground. This level was dug by the old company for nearly its whole length to very near the final depth. The bottom so reached has been in a measure refilled in places by the intrusion of the Chagres. The old company had given a width of only 22 meters (72.2 feet) to the bottom of the canal, and the excavation was thrown out in mounds on the shores by the dredging machines with long discharge pipes used in the work. In order to enlarge the section to the standard one now adopted, those spoil banks must be removed. The new company thought that, to save at the outset a large expense, they could accept for the present that bottom width of 22 meters (72.2 feet), and wait until after the opening of the canal for the enlarging of the same by easy dredging operations.

It is under these conditions that the excavation to be made now in that level was calculated. It is as follows:

	Cubic meters.	Cubic yards.
Excavation in ordinary soil.....	5, 870, 000	= 7, 678, 000
Excavation in rocky ground	538, 000	= 703, 700
Total.....	6, 408, 000	= 8, 381, 700

Of this amount we may expect that 4,800,000 cubic meters (6,278,000 cubic yards) can be excavated directly with dredging machines.

Bohio level.—The excavation necessary to form a channel of a bottom width of 50 meters (164 feet) across Lake Bohio, of which this level is a part, is as follows:

	Cubic meters.	Cubic yards.
Earth excavation	6, 350, 000	= 8, 306, 000
Rock excavation.....	2, 000, 000	= 2, 616, 000
Total.....	8, 350, 000	= 10, 922, 000

A portion of the earth excavation can undoubtedly be made with dredging machines.

Summit level.—The excavation necessary to form this level, according to the cross section indicated in article 3, is as follows:

	Cubic meters.	Cubic yards.
Earth excavation	6, 250, 000	= 8, 175, 000
Hard or rocky excavation	17, 600, 000	= 23, 021, 000
Total	23, 850, 000	= 31, 196, 000

In this total the excavation of the Culebra proper, between (P. K. 53.6) and (P. K. 55.5), is 11,200,000 cubic meters (14,650,000 cubic yards), and, inasmuch as under the old company nearly all of the clayey materials of the upper stratum was excavated, the above amount represents almost entirely an excavation in hard or rocky ground.

The spoil banks for this large excavation will probably be formed for the Culebra in the Lirio Valley upstream and the Quebrada Mallejon Valley downstream; they are more than ample for the purpose.

For the Emperador the lateral depressions along the line of the cut can be utilized; also the Rio Mandingo Valley, which is situated at the upstream extremity and will accommodate a large quantity of material.

Paraiso level.—This level, 2,427 meters (7,962.7 feet) long, between the Paraiso lock and Pedro Miguel ladder, will require:

	Cubic meters.	Cubic yards.
Earth excavation.....	759, 600	= 993, 600
Rock excavation	693, 400	= 907, 000
Total	1, 453, 000	= 1, 900, 600

Pedro Miguel level.—This level, 2,117 meters (6,945.6 feet) long between the Pedro Miguel and the Miraflores locks, will require:

	Cubic meters.	Cubic yards.
Earth excavation	617, 600	= 807, 800
Rock excavation.....	450, 000	= 588, 600
Total	1, 108, 400	= 1, 396, 400

Pacific level.—The digging of this level will require:

	Cubic meters.	Cubic yards.
Earth excavation	9, 051, 000	= 11, 839, 000
Rock excavation	588, 000	= 769, 100
Total	9, 639, 000	= 12, 608, 100

The greatest part of the earth excavation can be done with dredging machines, but it must be carried away quite a distance, thus destroying in part the advantages of that method of excavation.

SUMMARY.—The general excavation required for the digging of the canal proper is summarized in the following table:

Level.	Excavation.					
	Earth.		Hard and rocky.		Total.	
	<i>Cu. meters.</i>	<i>Cu. yards.</i>	<i>Cu. meters.</i>	<i>Cu. yards.</i>	<i>Cu. meters.</i>	<i>Cu. yards.</i>
Atlantic maritime	5, 870, 000	7, 678, 000	538, 000	703, 700	6, 408, 000	8, 381, 700
Bohio	6, 350, 000	8, 306, 000	2, 000, 000	2, 616, 000	8, 350, 000	10, 922, 000
Summit	6, 250, 000	8, 175, 000	17, 600, 000	23, 021, 000	23, 850, 000	31, 196, 000
Paraiso	759, 600	993, 600	693, 400	907, 000	1, 453, 000	1, 900, 600
Pedro Miguel	617, 600	807, 800	450, 800	588, 600	1, 108, 400	1, 396, 400
Pacific maritime	9, 051, 000	11, 839, 000	588, 000	769, 100	9, 639, 000	12, 608, 100
Total	28, 897, 200	37, 799, 400	21, 870, 200	28, 605, 400	50, 808, 400	66, 404, 800

The above quantities were calculated by means of cross sections made before beginning the actual work on the central cut. The excavation made in that cut is about 3,000,000 cubic meters (3,924,000 cubic yards), and is included therein. They will compensate supplementary quantities not now calculated but expected from causes that we can not exactly determine to-day, such as possible landslides and extra widenings to be given the canal at some curves. The same can be said of the dredgings just finished for the ingress channel and the port of La Boca, which amount to about 2,000,000 cubic meters (2,616,000 cubic yards).

Paving canal slopes.—It will be necessary, to insure stability for the slopes of the canal at certain points, to face them with masonry. We can not determine to-day the size and extent of that facing, the necessity for which will be disclosed only at the very time of excavating.

A general facing, however, has been provided for the slopes of the wetted prism in the summit level, from the berm which has been located 2.50 meters (8 feet) below the maximum water surface.

The quantity of cement concrete masonry required for this facing is 69,500 cubic meters (90,900 cubic yards), which was doubled to cover the revetment work which may be found necessary at other points.

ARTICLE 7.—Structures.

The principal structures are:

First. The locks.

Second. The dams which accompany them and close the several levels. These dams are accompanied with spillways to facilitate the escape of surplus water.

Locks.—The general arrangement adopted for the locks was summarized in article 4; only the peculiarities of their construction are to be now considered. The cost was calculated in the hypothesis of the immediate building of both chambers, 25 (82 feet) and 18 (59.1 feet) meters wide, respectively.

Under the title of general expense the increased expense arising from the widening of the narrower chamber to 25 meters (82 feet) will be mentioned, as well as the temporary reduction which would follow the postponement of the construction of the narrower chamber.

On account of the difficulty of securing the services of a great number of masons on the isthmus, it was thought proper to exclude, as much as possible, stone from the structures and to substitute concrete masonry, which does not require skilled labor.

The copings, hollow quoins, gate recesses, and sills are of hard stone, which are to be forwarded from Europe all cut. Most of the locks are located in knolls almost entirely of rock, so the side walls may be simply formed with a strong facing applied against the sides of the cuts. In that case the facing would be 3 meters (9.8 feet) thick.

When the side walls have to resist earth pressure, their thickness is calculated according to ordinary methods, allowing a minimum pressure of 6 kilograms per square centimeter (85.3 pounds per square inch).

The dividing wall was calculated according to the method used for a masonry dam, supposing one of the chambers to be empty and the other full.

A general floor in the shape of an inverted arch is provided between the side walls. The heads of the side walls are provided with recesses to receive floating gates, which are to act as water-tight doors in case of repairs to be made to the several parts of the locks. The special arrangement for each group of locks is as follows:

Bohio locks.—These locks consist of a double-stepped structure located in a knoll formed of a volcanic conglomerate of various rocks cemented with petrified sand. This ground makes a good resisting foundation and is of sufficient length to admit a double step of two locks. At either end it suddenly disappears under sandy and peaty

soil. The total length occupied by the masonry of these stepped locks is 603 meters (1,978.4 feet). The height of the largest gates on the downstream side of each chamber is 22.8 meters (74.8 feet), thus divided:

	Meters.	Feet.
Projection over maximum water elevation.....	0.5	= 1.6
Distance from maximum water elevation to top of sill.....	22	=72.2
Rest against sill.....	.3	= 1
Total.....	22.8	=74.8

The width of the gates for the larger chamber is 27 meters (88.6 feet), including 1 meter (3.3 feet) rest against each side wall. The gates of the smaller chamber are 20 meters (65.6 feet) wide. These sizes relate to the gates of all the locks.

The estimated quantities for this group of locks are as follows:

Excavation.....	1,031,000 cubic meters (1,348,600 cubic yards).
Masonry.....	432,300 cubic meters (565,500 cubic yards).
Lock gates.....	3,805 square meters (40,957 square feet).
Cast-iron pipes.....	11,700 meters (38,390 feet).
Cylindrical valves.....	16

Obispo locks.—These locks are also arranged in two steps for a total maximum fall of 15.25 meters (50 feet); they are to be built in a compact mass of volcanic rock. The total length of the masonry will be 603 meters (1,978.4 feet), as before. It would be easy to build on the same location a treble step of locks. The height of the larger gates is in this case 19.25 meters (63.2 feet).

The estimated quantities for this group of locks are as follows:

Excavation.....	967,000 cubic meters (1,265,000 cubic yards).
Masonry.....	372,000 cubic meters (486,600 cubic yards).
Lock gates.....	3,230 square meters (34,770 square feet).
Cast-iron pipes.....	1,700 meters (5,580 feet).
Cylindrical valves.....	16

Paraíso lock.—This lock, to be built on a rock foundation, will be 337 meters (1,105.7 feet) long. The arrangement of the several parts is the same as in the preceding locks. The maximum fall it is intended to overcome is 9 meters (29.5 feet) and the height of the larger gates will be 19.8 meters (65 feet).

The estimated quantities for this lock are as follows:

Excavation.....	570,000 cubic meters (745,600 cubic yards).
Masonry.....	215,000 cubic meters (281,250 cubic yards).
Lock gates.....	1,905 square meters (20,510 square feet).
Cast-iron pipes.....	850 meters (2,790 feet).
Cylindrical valves.....	10

Pedro Miguel locks.—The locks provided at this point are in two steps, with a maximum fall of 18 meters (59.1 feet).

They will be built upon a rock foundation; the total length of the masonry is 603 meters (1,978.4 feet). The height of the larger gates is 19.8 meters (65 feet).

The estimated quantities for this group of locks are as follows:

Excavation.....	687,300 cubic meters (899,000 cubic yards).
Masonry (aggregate).....	404,500 cubic meters (529,100 cubic yards).
Lock gates.....	3,275 square meters (35,255 square feet).
Cast-iron pipes.....	1,700 meters (5,600 feet).
Cylindrical valves.....	16

Miraflores lock.—This lock will cover a total length of 337 meters (1,105.7 feet), and, like the others, will have a rock foundation.

It will serve as a tide lock and will have a variable fall of from 9.25 meters (30.4 feet) at the time of the lowest tides, with regard to the maximum elevation of water in the preceding level, to 2.25 meters (7.4 feet) at the time of the highest tides. The height of the large gates will be 20.05 meters (65.8 feet).

The estimated quantities for this lock are as follows:

Excavation.....	362,800 cubic meters (474,600 cubic yards).
Masonry (aggregate).....	228,680 cubic meters (229,150 cubic yards).
Lock gates.....	1,900 square meters (20,460 square feet).
Cast-iron pipes.....	850 meters (2,790 feet).
Cylindrical valves.....	10

Dams and spillways.—The locks are all connected with earth dams, the object of which is to fill any depressions on either side of the canal and to thus close up the several levels. The conditions of execution vary according to local circumstances; they are summarized below. The plans give the fullest information.

Bohío works.—There will be constructed at Bohío:

First. A dam across the valley of the Chagrés, abutting on the left against the "Bohío Hill," so called, in which the locks are located, and on the left against the "Cemetery Hill," so called.

Second. A spillway to let out, in time of freshet, from the surplus water not retained in the lakes, a volume of 500 cubic meters (17,700 cubic feet) per second in the channels built by the old company on the left of the canal to the sea, some parts of which only remain to be completed.

This spillway will be located in a hollow formed by "Cemetery Hill."

Third. A spillway to let out at least 700 cubic meters (24,700 cubic feet) per second in the channels provided, or to be provided, to the right of the canal, and through them in the very bed of the Chagres at a point where the river completely diverges from the line of the canal.

This spillway will be built in a depression of land formed by the Rio Gigante gap; the escaping water will first flow in the swamps of Pena-Blanca to the right of the canal between P. K. 20.5 and P. K. 21.5.

The Bohio level, which forms a vast lake, the object of which is to temporarily retain a portion of the freshets up to 150,000,000 cubic meters (5,297,000,000 cubic feet), as explained in chapter 1 of this report, will have a variable surface which may reach a maximum elevation of 20 (65.6 feet) or fall to a maximum elevation of 16 (52.5 feet).

A layer, 1 meter thick, is to be stored in it at the beginning of the dry season to face possible losses through evaporation or percolation; the normal elevation of this level is therefore 17 (55.8 feet). The 3-meter (9.8 feet) layer between this elevation and elevation 20 (65.6 feet) has an approximate area of 5,000 hectares (12,360 acres), and will consequently impound 150,000,000 cubic meters (5,297,000,000 cubic feet).

The dam to be built across the Chagres will retain 20 meters (65.6 feet) of water above its bed which here is at about elevation zero. It will be brought up to elevation 23 (75.5 feet) with an additional height of 3 meters (9.8 feet) above the maximum water elevation in the lake. Numerous test pits sunken to great depths on the line and in the neighborhood of the proposed dam did not show any rock in the middle of the valley. It is therefore necessary to build here an earth dam. The geological section shows that the underground formation is favorable to a work of that character. The clayey puddle forming the bottom of this dam can be started at mean elevation -15 (-49.2 feet) in a compact argillaceous formation or an impermeable sandy clay bed constituting a thick layer resting on a very compact bottom of argillaceous sand and gravel.

This dam will have a length of 392 meters (1,286.1 feet) at top. The cross section shows the arrangement adopted for construction.

The object of the great mass of riprap against its downstream slope up to elevation 16 (52.5 feet) is mainly to permit great freshets to submerge the structure during construction without any danger of destruction or even of great damage. This may happen only in the hypothesis of the dam not having been completed to elevation 14 (45.9 feet). When that elevation is reached, the contemplated spillways at elevation 10 (32.8 feet) or 11 (36.1 feet) where rock is met upon which to rest their foundations, would then be stripped to the rock and the channels thus prepared would then allow free passage to the freshets.

The methods to be followed in the building of this dam were adopted at the sixty-seventh and ninety-fifth meetings of the engineering commission. It was then recognized that by reason of the unavoidable necessity of proceeding by gradual steps in the building of the locks, the dam, and spillways, the execution of the works for the closure of the valley at Bohio and for the regulation of the overflow of the lake would require no less than about ten years.

The spillways are to be of masonry and fitted with water-tight sliding metallic gates, such, for instance, as the "Stoney" gates used in the Manchester Canal.

The estimated quantities for these works, i. e., dams and spillways, are:

Excavation.....	1,057,800 cubic meters (1,384,000 cubic yards).
Puddled dam embankment.....	352,700 cubic meters (461,400 cubic yards).
Concrete masonry	34,050 cubic meters (44,550 cubic yards).
Dry masonry	18,900 cubic meters (24,750 cubic yards).
Riprap.....	39,800 cubic meters (52,100 cubic yards).
Timber for sheet piling	3,260 cubic meters (4,270 cubic yards).
Iron work.....	213,500 kilograms (470,700 pounds).
"Platelages".....	370 square meters (3,990 square feet).
Gate system.....	425 square meters (4,580 square feet).

Obispo dam.—The Obispo locks, at the end of the summit level on the Atlantic side, are connected with a dam closing the Rio Obispo Valley, thus making this rio a part of the summit level itself.

The location of this dam is in rock throughout, and the structure is to be of concrete masonry.

Its lowest foundations are at elevation 13 (42.6 feet); the surface of the water it retains being at a maximum elevation of 31.25 (102.5 feet), it will rise 18.25 meters (59.9 feet) above the lowest point of the dam. The length at top of this dam is 100 meters (328.1 feet); a spillway 50 meters (164 feet) long, with gates, is there provided. Its sill is at elevation 30.5 (100.1 feet), and, without the water reaching a higher elevation than 31.25 (102.5 feet), it will accommodate the flow of 70 cubic meters (2,500 cubic feet) per second in case the elevation of the water in the level becomes excessive. The section of the dam is established according to the best rules in use to-day.

The estimated quantities for this dam are thus resumed:

Excavation.....	4,460 cubic meters (5,850 cubic yards).
Masonry	8,000 cubic meters (10,500 cubic yards).
"Platelages" in wood.....	440 square meters (4,750 square feet).
Ironwork	20,000 kilograms (44,100 pounds).
Gates	52 square meters (559.7 square feet).

Paraiso dam.—The Paraiso locks, at the end of the upper level, on the Pacific side, are likewise connected with a dam in the depression formed by the Rio Grande Valley. This structure, of little importance, is to be on a rock foundation, and is to be of concrete masonry. Its length at top is 99 meters (324.8 feet) and its greatest height 8 meters (26.3 feet).

A spillway, with regulating gates, is provided outside from the dam to assist, if necessary, in carrying away the excess of water from the level. The regulating gates of this spillway occupy a space 35 meters (114.8 feet) long; their sill is at elevation 30.5 (100.1 feet), and their flowing capacity is 50 cubic meters (1,765 cubic feet) per second under the head corresponding to the maximum elevation of the level.

The estimated quantities for this dam are as follows:

Excavation.....	442,700 cubic meters (579,100 cubic yards).
Masonry	5,200 cubic meters (6,800 cubic yards).
"Platelage".....	60 square meters (650 square feet).
Ironwork	7,000 kilograms (15,450 pounds).
Gates	36 square meters (387.5 square feet).

Pedro Miguel Dam.—The group of locks at this point is also to be accompanied with a dam for the closure of the Rio Grande Valley, which here again intercepts the canal. The formation not being favorable for the building of a masonry dam, an earth dam is contemplated. Its greatest height will be 9.75 meters (32 feet) from water elevation. Its length at top will be 389 meters (1,276.3 feet). The greatest portion will have only an inconsiderable height.

This dam is to be built to the right of the canal; to the left, in the rocky cut of the Panama Railroad, the location of which is to be changed, a masonry spillway 47 meters (154.2 feet) long at top will be placed.

The estimated quantities for these structures are:

	Cubic meters.	Cubic yards.
Excavation	47,950	= 62,750
Embankment.....	111,900	= 146,400
Masonry	690	= 910
Riprap	7,500	= 9,850

Miraflores dam.—The Miraflores lock is connected with a dam closing again a low part of the Rio Grande Valley. It is to be a small masonry structure of a total height, at water level, not exceeding 5 meters (16.4 feet); its top length will be 96.5 meters (316.6 feet).

Estimated quantities:

	Cubic meters.	Cubic yards.
Excavation	860	= 1,125
Masonry	1,000	= 1,310

ARTICLE 8.—Feeding system and appurtenances.

As stated in chapter 1 of this report, the method for feeding the canal adopted and herein described consists of a derivation of the Chagres from a high point in the valley at Alhajuela, where a dam is to be erected. A reservoir will thus be formed which will be in communication with the summit level of the canal by means of a supply channel to be built on the side hills along the left side of the valley.

The structures required by the feeding system are:

First. The retaining dam at Alhajuela.

Second. The supply channel from the dam to the summit level.

Alhajuela dam.—The object of the contemplated dam is not merely to raise the level of the Chagres to a point high enough for supplying the connecting channel. It is farther reaching, and, as stated in chapter 1, includes the formation of a large reservoir lake, in which shall be impounded, besides the water necessary for feeding the canal and for the motive power required for its operation during the periods of scarcity of water in the river, which may last three months, a portion of the maximum output of the freshets, so calculated as to allow the flow in the lower valley of those volumes only which are not considered excessive for the proper regulation of the river.

The dam is to be located at a narrow and favorable point of the Chagres Valley, nearly 15 kilometers (9.32 miles) in a straight line from the place where the river first meets the line of the canal (P. K. 45). There we find a compact rock formation, the greatest depth of which is about 9 meters (29.5 feet) below the low-water mark of the Chagres, which is at elevation 28.4 (93.2 feet).

The lake to be formed by this dam, with a flow line at elevation 61 (200.2 feet), has an area which the surveys show to be 2,300 hectares (5,690 acres).

The water surface in the feeding channel at the start is at elevation 58 (190.3 feet), and this compared with elevation 31.25 (102.5 feet), maximum elevation of the water surface in the upper level, gives a fall of 16.75 meters (55 feet) for a length of about 15.5 kilometers (9.6 miles). The reserve to be stored up for the feeding of the canal and for the production of power, as well as to make good the natural loss in the lake itself during the period of scarcity of the Chagres, is estimated to be 130,000,000 cubic meters (4,600,000,000 cubic feet). This reserve would require a layer 5 meters (16.4 feet) high from elevation 58 (190.3 feet), which leads to elevation 63 (206.7 feet).

Above this last elevation must be stored up 100,000,000 cubic meters (3,532,000,000 cubic feet) to be diverted from the freshets, according to the provisions made for their regulation, which will require another layer 4 meters (13.1 feet) high and leads to maximum elevation 67 (219.8 feet) for the water surface in the lake.

The top of the wall is established at elevation 69 (226.4 feet), and it is, besides, surmounted with a parapet 1 meter (3.3 feet) high. Low water in the Chagres being there at elevation 28.4 (93.2 feet), the depth of water impounded will be about 39 meters (128 feet).

The lowest point of the foundations being at about elevation 19 (62.3 feet), the greatest height of the dam will be about 50 meters (164 feet) above the foundations; its top length will be 285.5 meters (936.7 feet).

This structure is expected to be built entirely of concrete masonry. Its section was calculated according to the best rules followed to-day in such a manner that the maximum pressure will not exceed 6.5 kilograms per square centimeter (92.5 pounds per square inch), which is very reasonable.

In connection with this structure a spillway is to be excavated in the plateau at elevation 75 (246.1 feet), which crowns the rocky knoll forming on the left bank of the Chagres one of the abutments of the dam.

The drawings give all the necessary indications for the intended disposition of these structures.

Moreover, the minutes of the sixty-ninth and ninety-fifth meetings of the engineering commission completely relate the means adopted for the mode of execution. We will only repeat here that, in order to render easily accessible the section of country to be occupied by the dam, its appurtenances, and the feeding channel, a railroad is expected to be built between Obispo and Alhajuela.

The time required for the building of the Alhajuela Dam has been, according to data presented at the meetings above referred to, estimated at five years.

Estimated quantities for Alhajuela Dam:

	Cubic meters.	Cubic yards.
Earth excavation	51,400	= 67,250
Rock excavation.....	18,900	= 24,700
Masonry	150,000	= 196,200

The execution of this dam will require the excavation of a tunnel of "derivation" for the waters of the Chagres and of a temporary dam to throw the waters in that tunnel, which will be 300 meters (984.3 feet) long and will have a section of 77 square meters (828.8 square feet).

The spillway is to be dug entirely in the rock; it will have a clear length of 50 meters (164 feet), allowing an overflow of 700 cubic meters (24,700 cubic feet) per second, and will be provided with metallic gates of the same type as adopted at Bohio. The sill of those gates will be at elevation 59 (193.6 feet) and the top at elevation 63 (206.7 feet).

The building of this spillway will require quite an amount of rock excavation, which may, however, be utilized in great part for the masonry of the dam.

The estimated quantities for the spillway are as follows:

Rock excavation	109,200 cubic meters (142,850 cubic yards).
Masonry	450 cubic meters (590 cubic yards).
"Platelage"	150 square meters (1,620 square feet).
Gates	210 square meters (2,260 square feet).
Ironwork	80,000 kilograms (176,370 pounds).

Feeding channel.—The channel is designed to supply at the outlet 25 cubic meters (890 cubic feet) per second. The plans are such that it will be possible to increase this supply by 10 cubic meters (350 cubic feet) by allowing the water to rise 0.5 meter (1.6 feet) higher, which can be done by raising the lip of the overflow openings provided at intervals over the whole length of the channel.

The surface of the water at the intake is established at elevation 58 (190.3 feet); it is the minimum flow line of the Alhajuela Reservoir.

The territory traversed by the location of the channel is divided into three very distinct portions with regard to the general lay of the ground.

The first portion of the channel, that between the intake at Alhajuela and the Chilibre Valley, covers a length of about 3.5 kilometers (2.17 miles). It is generally a kind of rocky plateau, cut up by several very tortuous rios, forming steep ravines. It would be very difficult and expensive to attempt in this region to excavate the channel on the side hills by following the meanderings of these rios. The solution arrived at and which leads to structures of simple character consists in directly crossing the plateau while keeping near its edge on the side of the Chagres Valley, and in damming up, as we proceed, the ravines which cut it up, thus forming little lakes through which the channel will cross these ravines. The parts of the plateau too high above the channel bottom will be tunneled. The total length of the tunnels in this region which extends to P. K. 3.5 is 595 meters (1,952.1 feet). The dams, all built in masonry upon rock found at very shallow depths, with some retaining walls at a few secondary depressions, will require together 8,500 cubic meters (11,120 cubic yards) of masonry.

The intended railroad follows closely the location of the channel, and it will only be necessary to build a few short Decauville branches to give access to the works.

The second section of the channel includes the crossing of the valley of the Chilibre, an important affluent of the Chagres, and of the Juan Mina, a secondary affluent near the former. Between the ends of that section the channel is, on an air line, about 3,150 meters (10,350 feet) long.

The section is located in a large depression very much lower than the elevation of the channel bottom if it were continued at its normal level across the valley. The most rational and at the same time the most economical plan appears to be across that valley by an inverted siphon composed of two parts, 1,400 (4,594 feet) and 610 (2,001 feet) meters long, respectively, connected with a section of open channel 1,140 meters (3,740 feet) long.

At the crossing of the Chilibre, an important metallic structure will be built to support the siphon. The three pipes of which it is formed have, under the total available head, a flowing capacity of 25 cubic meters (890 cubic feet) per second; the structures for the support and shelter of the siphon are so designed as to allow, if necessary, of the laying of a fourth pipe, thus increasing the capacity to 33 (1,165 cubic feet) or 35 cubic meters (1,240 cubic feet) per second.

The third section of the supply channel, along the accidental slope of a continuous ridge nearly parallel to the Chagres, is located on the sidehill. This slope is cut at several points by somewhat deep depressions, forming secondary thalwegs perpendicular to the general direction of the ridge. The plans adopted for the crossing of these depressions vary according to circumstances. In some cases the chasm is to be bridged by a flume; in others it appeared simpler and more economical to adopt the solution already applied to the first portion, which consists in damming the rio at the crossing of the supply channel, and in forming a small lake; these works are nowhere of magnitude, and the conditions for the foundations are favorable in all cases.

The channel intersects at several points of this section high spurs which it would have been expensive and possibly dangerous to cross in open cuts; they are to be crossed by means of short tunnels. This section at its downstream terminus ends in a spur at elevation 75 (246.1 feet) which separates the secondary valley of Rio Gamboa from the valley of the other rio flowing into the summit level of the canal. There is no other way of crossing this spur than by a tunnel which will be 430 meters (1,410.8 feet) long.

The location just described, prepared for the scheme with the bottom elevation of the summit level at 29.5 (96.8 feet), applies as well to the plan with the summit at elevation 20.75 (68.1 feet), for which it was thought best to preserve the same general features of the channel. In fact, if it were desired to lower the elevation of the outlet, it would be necessary to greatly lengthen the last tunnel, without realizing a material saving anywhere else on the route of the channel or simplifying any of the structures; on the contrary, by allowing it to end at the same elevation, we can command a 9 meters (29.5 feet) fall, thus creating a source of power without additional expense.

SPECIAL TECHNICAL CONDITIONS.

The feeding or supply channel includes four kinds of work, namely:

First. Excavation for the channel.

Second. Retaining walls and masonry dams.

Third. Earth levees and dams.

Fourth. Various other structures.

EXCAVATION AND CROSS SECTION OF THE CHANNEL.

Almost everywhere the channel is in a cut, so that it will be naturally as water-tight as possible; only at the rio crossings and at some points where it was economical to simply follow the side hills it was found necessary to build dams and side walls, which, however, are generally of small magnitude.

The total length of the channel is 15,250 meters (9.48 miles) between Alhajuela Lake and the regulating dam at the lower end, from which it will empty into a basin, forming, as it were, an estuary into the summit level.

The bottom of the channel at the start is at elevation 55.5 (182.1 feet); its slope is regularly 0.8 meter per kilometer (4.22 feet per mile) in the portions where the sides are of earth or of rock not paved, and of 0.6 meter per kilometer (3.17 feet per mile) in the tunnels and flumes. The slope was also reduced to 0.6 meter per kilometer (3.17 feet per mile) in the open channel between the two siphons of Chilibre Valley. The bottom of the channel at its lower end is at elevation 38.78 (127.2 feet). Beyond that point the channel formed by the upper level is at about elevation 37 (121.4 feet). The plan of the channel is a series of tangents and curves, the radii of which are not less than 60 meters (196.9 feet).

The cross sections of the channel are of two kinds for the portion in open cut; the engineering commission particularly discussed, at its ninety-first meeting, the question of cross sections, which have been computed by means of the latest Bazin formula, which insures a flow of at least 25 cubic meters (890 cubic feet) per second. Besides, an extra height of 1 meter of water is arranged for, which would increase the supply to at least 40 cubic meters (1,400 cubic feet) if necessary. The channel is, therefore, well able to meet any possible present and future requirement.

RETAINING WALLS AND MASONRY DAMS, ALSO EARTHEN LEVEES AND DAMS.

Where the channel has to cross a rio or a depression not exceeding 5 (16.4 feet) or 6 (19.7 feet) meters below the normal water elevation, a lateral dam is provided to replace the omitted side walls. These dams are masonry walls at points where they can be built on rock foundation without incurring too great an expense; this is notably the case between the inlet of the canal and the Chilibre Valley; they are of earth at other points.

The masonry dams are 28 in number with a total quantity of 29,000 cubic meters (38,000 cubic yards) of masonry; they are of concrete masonry, and their section is calculated from the usual rules. In these structures spillways are provided of a size sufficient for the easy exit of the waters brought in by the dammed rios and quebradas, as well as by the flow from the sidehills.

The number of earth dams is 16, of a total approximate volume of 10,000 cubic meters (13,100 cubic yards); they contain 1,400 cubic meters (1,850 cubic yards) of puddled work. Like the masonry dams, they are so designed as to be perfectly secure.

At the outlet of the first siphon into the Chilibre Valley, the natural ground being at a lower elevation than that of the channel bottom, an earthen levee 230 meters (755 feet) long, with a height of from 0 to 5.7 meters (18.7 feet) is to be built. The whole of the wetted prisms will be entirely covered with clay puddle 0.6 meter (2 feet) thick. The estimated quantities in this levee are:

Earth, 62,000 cubic meters (81,110 cubic yards).
Clay puddle, 7,000 cubic meters (9,156 cubic yards).

VARIOUS OTHER STRUCTURES.

The other structures include two inverted siphons, two bridge flumes, one bridge over the Rio Chilibre, and three smaller ones to be located either in the Chilibre Valley or at the crossing of the Rio Juan Mina.

Each siphon is formed of three sheet-steel pipes 2.4 meters (7.9 feet) diameter, placed side by side, with intervening spaces of 0.5 meter (1.6 feet) for repairs. The heads of these pipes are inserted in masonry dams, and are each fitted with a gate, in view of independent service. There are waste gates at the lowest point of each pipe.

The length of the first siphon is 1,400 meters (4,600 feet), with a loss of head of 5.2 meters (17.2 feet). The radius of the pipes being 1.2 meters (3.9 feet), their aggregate flowing capacity, according to the method of calculation generally used in the department of the Paris waterworks, is 26.09 cubic meters (921.4 cubic feet).

The length of the second siphon is 610 meters (2,001 feet), with a loss of head of 2 meters (6.6 feet) and an aggregate flowing capacity of 29.16 cubic meters (1,029.8 cubic feet).

The necessary supply is consequently well insured. Moreover, the substructure, as previously stated, is ample enough to accommodate a fourth pipe.

The siphons rest upon concrete foundations by means of intervening cast-iron shoes.

At the crossing of streams, culverts are provided for the flow thereof. Two flumes bridge the Rio Falupa (P. K. 9.128) and the Rio Falupita (P. K. 10.1), respectively, and present a section sufficient for the supply.

TUNNELS.

In order to avoid expensive detours which the location of the channel over very steep sidehills would have required, fourteen small tunnels are contemplated, with a total length of 1,555 meters (5,101.8 feet). The wetted part of these tunnels is to be lined. The upper part may also be lined, if necessary.

The cross section of these tunnels is calculated by M. Bazin's formula and will largely meet all wants.

MEANS OF ACCESS TO THE WORKS.

In order to execute the various works just explained, storage yards for materials will be provided at convenient points near the branch railroad from Gamboa to Alhajuela; then from these yards to the works, "Decauville," narrow-gauge branches will be built to facilitate the necessary handling of materials at the works.

These branches will have a total length of about 5,000 meters (16,400 feet).

The following table is a summary of the estimated quantities for the proposed feeding channel:

General excavation:	
Earth	232,000 cubic meters (303,500 cubic yards).
Rock	386,000 cubic meters (505,000 cubic yards).
Earthen levees and dams between the siphons:	
Embankment	72,000 cubic meters (94,200 cubic yards).
Clay puddle	8,400 cubic meters (11,000 cubic yards).
Various tunnels	1,555 meters (5,101.75 feet) long.
Dams and masonry walls of concrete masonry	29,000 cubic meters (38,000 cubic yards).
Siphons in Chilibre Valley, with three pipes, foundation, and covering ..	2,010 linear meters (6,600 feet).
Metallic trestle supporting the siphon over the Chilibre	45 linear meters (148 feet).
Bridge flume over the Falupa and the Falupita	90 linear meters (295 feet).
Branches of Decauville Railroad to give access to the several works	5,000 linear meters (16,405 feet).

ARTICLE 9.—Upper Chagres Railroad.

The railroad contemplated to facilitate the access to the whole region, including the supply channel and the Alhajuela Dam, starts near Gamboa from a branch connected with the Panama Railroad and already built along the central cut of the canal. Its terminus will be the plateau, which at elevation 75 (246.1 feet) commands the site of the Alhajuela Dam, and upon which will be built the houses for the laborers and all other necessary buildings and appliances.

The location of this road, a plan and profile of which have been made, was studied so as to bring it close to all the points of the channel where structures require the incoming of materials. The cross sections show that it will be built over ground having easy transverse slopes. The earthworks required will not be large. It will be easy to build close to the road laborers' camps and other buildings required by the contractors and for the storage of materials.

The gauge of this branch road will be the standard of the Panama Railroad. The minimum radius of the curves is 150 meters (492.1 feet). Its length is 16.2 kilometers (10.07 miles).

An estimate of quantities is as follows:

Excavation:	
Earth	125,500 cubic meters (164,150 cubic yards).
Rock	32,000 cubic meters (41,900 cubic yards).
Embankment:	
From excavation	157,500 cubic meters (206,010 cubic yards).
Borrowed	12,800 cubic meters (16,750 cubic yards).
Excavation for foundations of structures	3,900 cubic meters (5,100 cubic yards).
Masonry, total	8,630 cubic meters (11,290 cubic yards).
Metallic trestle over La Falupa and La Falupita	33 meters (102.27 feet).
Metallic trestle over Chilibre	43 meters (141.08 feet).
Metallic trestles over minor openings	103 meters (337.93 feet).

The building of this branch road is estimated to require two years.

ARTICLE 10.—*Dispositions adopted for the regulation of the freshets of the Chagres—"Derivations," widenings.*

The general features of the plan adopted for the disposition of the freshets of the Chagres were indicated in chapter 1 of this report. They consist, mainly:

First. In providing for the free flow during the period of maximum flood of an amount of at least 1,200 cubic meters (42,380 cubic feet) per second through the Bohio spillways and through special channels to the right and left of the canal.

Second. In retaining the surplus of the floods, which is estimated in the most unfavorable cases to be 250,000,000 cubic meters (8,829,000,000 cubic feet), in the Bohio Lake to an amount of 150,000,000 cubic meters (5,297,000,000 cubic feet) and in the Alhajuela Lake to an amount of 100,000,000 cubic meters (3,532,000,000 cubic feet), the amounts so impounded to be gradually released at the time of the subsidence of the floods.

There remains only to indicate the special arrangements adopted to meet these conditions.

Two spillways are provided at Bohio, one with a 54-meter (177.2 feet) opening on the left of the canal and with an estimated overflowing capacity of 500 cubic meters (17,700 cubic feet) per second; the other with a 78-meter (255.9 feet) opening on the right at the Rio Gigante gap, with an estimated overflowing capacity of 700 cubic meters (24,700 cubic feet) per second. These spillways are provided with movable gates 3 meters (8.8 feet) high, the sills of which are at elevation 14 (45.9 feet) and the top at elevation 17 (55.8 feet) when they are completely lowered. Generally the gates will remain lowered so as to maintain the water in the lake at elevation 17 (55.8 feet).

When a freshet shall occur the gates will be gradually raised, always maintaining that constant elevation while allowing the flow of all the incoming water, until the gates, being completely raised 3 meters (9.8 feet), the output of 1,200 cubic meters (42,380 cubic feet) per second will be reached; the total length of the spillways is calculated with that end in view. From that moment should the freshet continue and the overflow become greater than 1,200 cubic meters (42,380 cubic feet) per second, the gates would be gradually lowered so as to limit to that amount the quantity issuing through the openings, and the surplus would naturally be impounded in the lake, raising its surface about elevation 17 (55.8 feet). It may happen that the water may progressively reach elevation 20 (65.6 feet) if the freshet is very large; at that moment the gates shall have been completely lowered, their top being brought back to elevation 17 (55.8 feet), and the output of 1,200 cubic meters (42,380 cubic feet) per second will flow over the top under a 3-meter (9.8 feet) head; the length of the spillways is so calculated as to allow the flow of 1,200 cubic meters (42,380 cubic feet) per second under that head.

The storage of 150,000,000 cubic meters (5,297,000,000 cubic feet) will thus be obtained.

Similar arrangements are provided at the Alhajuela spillway for the impounding of 100,000,000 cubic meters (3,532,000,000 cubic feet), and a free maximum flow of 700 cubic meters (24,700 cubic feet) per second. It was, in fact, calculated from the data at hand that this amount, together with the volume naturally furnished to Lake Bohio by the watershed below Alhajuela, will give a total maximum flow (inflow) of 2,000 cubic meters (70,600 cubic feet) per second, out of which, 1,200 cubic meters (42,380 cubic feet) being freely allowed passage through the Bohio spillways, 800 cubic meters (28,250 cubic feet) will be retained and form, during the period of at most forty-eight hours, corresponding to the passage of a dangerous flood, the volume of 150,000,000 cubic meters (5,297,000,000 cubic feet) to be impounded.

To take care of 1,200 cubic meters (42,380 cubic feet) per second issuing from the Bohio spillways, "derivations" are provided to the left and right of the canal. These "derivations" were made in great part by the old company. They are merely to be repaired and completed. They are completely isolated from the canal, and levees will be built at such places where they will be deemed necessary to shelter the canal from any eventual intrusion of the waters carried in the "derivations." In case the output of 1,200 cubic meters (42,380 cubic feet), which they are to accommodate, would be accidentally overstepped, the flow of the surplus will take place in the main bed situated between the "derivations" and the protecting levees of the canal.

Widenings.—Lake Bohio contains some narrow and tortuous portions which the width of the canal would nearly fill. Unless those parts are widened currents dangerous to navigation might result. These narrow places are to be so straightened and widened that the possible flow at the time of the maximum inflow will not exceed an average velocity of 1 meter (3.3 feet) per second.

ARTICLE 11.—*Change of location of the Panama Railroad.*

The present railroad across the Isthmus intersects the line of the canal in two places. It does not seem advisable to allow a railroad to cross so important a canal, on account of the impediments which might result for navigation. Moreover, the elevation of the water in Lake Bohio, which is a part of the plans considered, is at places higher than the railroad track, which would thus be submerged. For these two reasons it is necessary to relocate the railroad and to keep it to the left of the canal, where it is now situated at its starting point at Colon and at its terminus at Panama. This change will begin a little below the site of the Bohio Dam and terminate at Miraflores, where it will meet again and follow the actual location. The final surveys for this change of location are not yet made; a preliminary location only has been made, which permits to approximately estimate the required expense at 250,000 francs (\$48,250) per kilometer. The total length of the new location will be about 50 kilometers (31 miles).

ARTICLE 12.—*General expense.*

The cost of the plan just described has been estimated carefully and in detail for all kinds of work. The estimate for excavations was established from calculations based upon numerous cross sections made especially for that purpose, and for the various structures, from complete drawings. The details may, at the time of actual execution, be more or less modified, but the estimated expense would not be practically changed thereby, but the unit prices adopted in our estimate would be perceptibly modified by probable improvements in the means of execution. We can, therefore, expect that such modifications would reduce the estimates, as the unit prices adopted are large.

The general cost is summed up as follows:

General excavation.

	Francs.	Dollars.
Maritime Atlantic level	20,568,000=	3,969,700
Bohio level	33,225,000=	6,412,500
Summit level	118,675,000=	22,904,300
Paraiso level	6,363,000=	1,228,100
Pedro-Miguel level	4,781,000=	922,700
Maritime Pacific level	30,387,000=	5,864,700
Contingencies	21,000,000=	4,053,000
Total	235,000,000=	45,355,000
Revetment of the canal	7,000,000=	1,351,000
General cost of excavating canal	242,000,000=	46,706,000

The average prices adopted, including labor and disposal of materials, are, for dredging, 3 francs (\$0.579) and exceptionally 3.5 francs (\$0.6755) per cubic meter for ordinary excavation, and 5.5 francs (\$1.0615) per cubic meter for the removal of rocky materials.

For the big trench and other dry excavation they are 3.5 francs (\$0.6755) for ordinary excavation and 5.5 francs (\$1.0615) for rocky excavation, including all labor and disposal of materials.

These unit prices were established from the actual cost of the large central cut, with corrections which appear to be justified by expected future conditions.

Locks.

	Francs.	Dollars.
Double step of twin locks at Bohio	32,216,000=	6,217,700
Double step of twin locks at Obispo	29,928,000=	5,776,100
Paraiso twin locks	15,945,000=	3,077,400
Double step of twin locks at Pedro Miguel	28,851,000=	5,568,300
Miraflores twin lock	15,799,000=	3,049,200
Timber approaches of locks and operating machinery	1,675,000=	323,300
Contingencies	12,586,000=	2,429,100
General expense for locks	137,000,000=	26,461,100

The price for masonry has been determined by a careful analysis of quantities and established at 50 francs (\$9.65) per cubic meter.

Dams and spillways.

	Francs.	Dollars.
Bohio dam and spillways, including temporary structures	10,981,000=	2,119,300
Obispo spillway dam	451,700=	87,200
Paraiso dam and spillway	1,348,700=	260,300
Pedro Miguel dam and spillway	896,900=	173,100
Miraflores dam and spillway	50,200=	9,700
Alhajuela dam and spillway, including temporary structures	12,210,700=	2,356,700
Contingencies	4,060,800=	783,700
General expense for dams	30,000,000=	5,790,000

The masonry prices are the same as for the locks, as regards the dams along the canal, and are raised to 60 francs (\$11.58) for the Alhajuela dam.

"Derivations" and widenings.

	Francs.	Dollars.
"Derivation" to the left of canal	5,547,000=	1,070,600
"Derivation" to right of canal	5,550,000=	1,071,200
Widening at various points of Lake Bohio.....	3,298,700=	636,600
Contingencies	1,604,300=	309,600
General expense for "derivations" and widenings.....	16,000,000=	3,088,000

Railroads.

	Francs.	Dollars.
Change of location of Panama Railroad	14,000,000=	2,702,000
Higher Chagres Railroad.....	1,617,000=	312,100
Contingencies	383,000=	73,900
General expense for railroads.....	16,000,000=	3,088,000

Feeding channel.

	Francs.	Dollars.
Estimated expense	15,000,200=	2,895,000
Contingencies	1,999,800=	386,000
General expense for the channel.....	17,000,000=	3,281,000
Estimated cost of right of way.....	6,000,000=	1,158,000
Estimated expense for power plants.....	13,000,000=	2,509,008
The aggregate of the expense above summarized represents a total of	477,000,000=	92,081,100
Contingencies on account of unforeseen structures, the need of which may develop during construction, in addition to the sums (nearly 42,000,000 francs) (\$8,106,000) already estimated for the rest of the work.....	35,000,000=	6,755,000
Total execution of canal and appertaining work.....	512,000,000=	98,836,100

This amount would be diminished by about 40,000,000 francs (\$7,720,000) if the building of a second chamber in all the locks were temporarily postponed.

The amount of 512,000,000 francs (\$98,836,100) would be raised to 525,000,000 francs (\$101,325,000) if both chambers, with a width of 25 meters (82 feet) each, were built at the start for each lock.

Dated Paris, November 16, 1898.

(Signed)

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(Signed)

A. ROBAGLIA,

President Engineering Commission.

HENRY L. ABBOT.

E. CASTEL.

V. DAYMARD.

FARGUE.

A. FTELEY.

FULSCHER.

HERSENT.

W. HENRY HUNTER.

KOCH.

JULES MARTIN.

C. SKALKOWSKI.

COMPARISON OF ADVANTAGES AND DISADVANTAGES OF THE THREE PROJECTS (ENLARGED) OF THE TECHNICAL COMMITTEE.

It will be assumed that, in respect to the water supply in the dry season and the regulation of the Chagres River in times of floods, all three projects stand on the same footing, and that they are equal in respect to time of completion; for although the amount of excavation in the Culebra division differs materially in each, the controlling feature that fixes the time of completion of the canal is the construction of the Bohio dam, locks and spillway, and these are identical in each project.

PROJECT III.

[Summit level, 62.31 feet.]

ADVANTAGES.

1. The summit level is lower than in either of the other projects.
2. The fluctuation in the level of Lake Bohio is less. This arises from the fact that in Project III the amount of water to be stored up in Lake Bohio during floods is less. In Projects I and II it was expected to store up in floods 150,000,000 cubic meters in Lake Bohio, whereas in Project III the amount to be stored up is only 100,000,000 cubic meters.
3. The less number of locks.
4. By reason of the fewer number of locks there is less danger of any interruption to navigation from their getting out of order. This advantage, however, is not great, because, the locks being in duplicate, it is not likely that both will be out of order at the same time.
5. The time of transit will be shorter. This is not an important advantage. The difference in time of transit is so insignificant when measured by the expense of running the vessel that it is almost negligible. The average tonnage of vessels passing through the Suez Canal is something over 3,000 tons. The cost per hour of a 3,000-ton ship running at full speed does not average more than about \$20. In the canal the speed will be reduced. For a steamer of 4,000 tons, \$25 per hour would be a fair average. A saving of two or three hours, therefore, in time of transit is almost too insignificant an item to merit consideration.
6. It approaches more nearly the sea level and consequently can be transformed into a sea-level canal, should it ever become necessary, in less time, with less inconvenience to commerce and at less cost than either of the other projects.
7. Projects II and I both require an artificial feeder for the summit level. In Project III, Lake Bohio will be supplied from Lake Alhajuela by the river itself without an artificial feeder. This is an important advantage.
8. The cost of maintenance will be less than in either of the other projects on account of the less number of locks and there being no artificial feeder.
9. Should the length, breadth and depth of vessels using the canal increase so that an increase in the size of locks should become necessary, it could be done more readily with five locks than with any greater number.

DISADVANTAGES.

1. Greater cost. This is an insignificant item and does not amount to more than about \$5,000,000 when compared with Project II, nor more than about \$10,000,000 when compared with Project I.
2. On account of the greater depth of the Culebra Cut there will be greater danger of slides. The deeper this cut the greater will be the difficulty of maintaining it. It is not possible to estimate what the additional cost of maintaining the cut will be, but it may safely be assumed that the cost of maintenance will be in direct proportion to its depth.

PROJECT II.

[Summit level, 97.6 feet.]

ADVANTAGES.

1. The summit level being lower than that in Project I, it has an advantage over the latter, but not over Project III.
2. The estimated cost is somewhat less than that of Project III.
3. The excavation in Culebra Cut is less than in Project III.

DISADVANTAGES.

1. As compared with Project III, it has a higher summit level.
2. It requires an artificial feeder to supply that level.
3. The use of a feeder, which may get out of order, is a disadvantage.
4. It requires two more locks than that of Project III.
5. The cost of maintenance will be greater than that of Project III.
6. On account of a greater number of locks there will be greater liability of their getting out of order.
7. There is a greater fluctuation in the level of Lake Bohio.
8. It will require more time, more money and will inconvenience commerce to a greater extent to transform it into a sea-level canal, should it ever become necessary, than Project III.

PROJECT I.

[Summit level, 126.31 feet.]

ADVANTAGES.

1. Less excavation in Culebra Cut.
2. Less estimated cost.

DISADVANTAGES.

1. High summit level.
 2. Greater number of locks than either of the other projects.
 3. Greater cost of maintenance, due to greater number of locks.
 4. On account of the greater number of locks there is greater danger of the canal being put out of order.
 5. As compared with Project III, it has the disadvantage of the artificial feeder.
 6. Liability of artificial feeder to interruption.
 7. Can not be as quickly transformed into a sea-level canal as either of the other projects.
- The accompanying portfolios, A and B, contain all the maps needful to a full understanding of the Report of the Technical Committee and of the Technical Notes (Appendix A) of which they formed a part.

Portfolio A contains a map of the canal region on a scale of $\frac{1}{50,000}$, in five sheets.

Portfolio B contains the following plates:

Plate 1.—General plan of the canal on a scale of $\frac{1}{50,000}$.

Plate 2.—Profiles of the projects which have the bed of the summit level at elevations 20.75 meters and 9.75 meters.

Plate 3.—Cross sections of the canal in the various materials.

Plate 4.—General plan of the region of Bohio.

Plate 5.—Locks at Bohio.

Plate 6.—Bohio dam in elevation and section.

Plate 7.—Bohio spillways.

Plate 8.—Paraiso lock.

Plate 9.—Dam and spillway at Alhajuela.

Plate 10.—General map of the upper Chagres, with the location of the feeder and railroad indicated thereon.

Plate 11.—Profile on line of feeder.

Plate 12.—Drawings of various works in connection with the feeder.

Plate 13.—Profile of railroad from Gamboa to Alhajuela.

Plate 14.—Railroad from Gamboa to Alhajuela, various types of cross sections and metallic bridge across the Chilibre.

Plate 15.—Study of a method of making the Culebra Cut (general and detail plans).

Plate 16.—Study of a method of making the Culebra Cut (cross sections).

Plate 17.—I. Graphic illustration of the number of laborers and mechanics needed to execute the works. II. Graphic representation of the distribution of expenses over a period of ten years for the 20.75 meters project.

APPENDIX A.

TECHNICAL NOTES CONCERNING VARIOUS PROJECTS ADOPTED FOR THE SOLUTION OF SEVERAL SPECIAL PROBLEMS IN THE CONSTRUCTION OF THE CANAL.

By M. LOUIS CHORON, Engineer in Chief of New Panama Canal Company.

INTRODUCTION.

The report of the technical committee of November 16, 1898, which was submitted to the board of directors of the company, has set forth the general and complex problems incident to the construction of a lock canal to join the two oceans through the Isthmus of Panama. Summing up the discussions of many sessions devoted to the study of this great problem, the committee has laid down those principles which should be adopted as bases of the final project, taking into consideration the limits within which to keep the expenses, the necessity of reducing the period of constructing the works to a reasonable time, the guaranties of a successful execution of the projected works, which must not be overlooked, and lastly, the chances of lowering the large central cut to greater or less depth without endangering the probable stability of the slopes and without risking serious disappointment respecting the period of construction.

After a careful examination the technical committee deemed the lock-canal project the one best fulfilling the requirements, and, among the several studies, the one including the large central cut, having its bottom elevated 20.75 meters above mean tide with a highest water level of 31.25 meters above the same. The difference in level between this and the oceans would be overcome on each slope by four locks, so placed on the Atlantic side as to form a single intermediate level, which would be the so-called central Lake Bohio, and on the Pacific side two intermediate levels. In this project the summit level would be fed from a dam at Alhajuela in the upper valley of the Chagres. This dam would raise the level of the river to the minimum elevation of 58 meters, and would form an immense reservoir having an area of 2,300 hectares in which to store the surplus waters necessary to feed the canal during the dry season when the regular discharge of the Chagres is insufficient for ordinary needs. This reservoir would communicate with the summit level by means of a feeder about 15 kilometers long. The project for this feeder is identical with that for the project having a bottom elevated 29.50 meters above sea level, mentioned below. No advantage would result from reducing its level in the project at 20.75 meters, either from a technical standpoint or in regard to its cost of construction. The fall thus obtained at its terminal point will be utilized as an important source of power.

In the 29.50-meter as well as in the 20.75-meter project the height of the Alhajuela dam would be raised sufficiently to provide, in addition to the volume necessary to feed the canal, a further capacity to hold back part of the volume of maximum discharge during excessive floods of the Chagres, thus reducing to a reasonable extent the discharge into the lower lake which constitutes one of the levels of the canal. This second lake, constituted by a dam at Bohio (P. K. 24 of canal), would have its normal level at elevation 17 meters. During the dry season it might fall to 16 meters, owing to natural losses, and the elevation of the bottom of the navigable channel through this lake would then be 7 meters above sea level. In time of large floods the function of this lake, concurrently with the Alhajuela Lake, would consist in regulating and in moderating the flow by holding back momentarily part of the maximum discharge, which would raise its surface to the maximum level of 20 meters. The lowest water level of the Chagres being about at elevation 0 meter at the point where the dam would be built, it follows that the dam would have a maximum pressure, due to the height in the lake, of 20 meters. It would be a so-called earth dam, because the character of the foundation does not lend itself to the construction of a masonry dam. The discharge at the outlets of the lake, thanks to the system of storing provided, would be limited to a maximum of 1,200 cubic meters per second in time of the largest floods, and this discharge in the region extending between the Bohio dam and the ocean would be regulated by means of special channels, either natural or artificial, on both sides of the canal, under such conditions as would protect the canal against any invasion.

This is a short analysis of the project devised by the technical committee, which is described in its essential features in the second chapter of its report. Concurrently with this project the committee retained, after a study of all the variants, two other plans intimately connected with

the first as regards the provisions adopted and derived therefrom, either for deepening more or for deepening less the central cut.

In the former variant it suffices to add a lock at each end of the summit level in addition to those provided in the above project; in the latter variant, on the contrary, these latter locks would be suppressed and the summit level, identified with the Lake Bohio itself, would extend from the Bohio locks to the Pedro-Miguel locks. In the former of these variants the bottom of the summit level would be elevated to 29.50 meters and would be fed exactly as in the project favored; in the latter the bottom of the summit level would be reduced to 9.75 meters above sea level and, being identified with Lake Bohio, would be fed directly by the discharge of the Chagres into this lake coming from the Alhajuela dam. This dam would be maintained to provide a reservoir both for a reserve water supply during the dry season and for regulating the volume of heavy floods before their discharge into the summit level. These two projects, and the intermediate project above described, have been studied and discussed with equal care by the committee and found to be equally satisfactory for the needs of navigation. From a comparison of their respective conditions it appears beyond question that the latter project, which provides the lowest summit level, and by which the canal would be supplied with water without a feeder, would be preferable were it possible to complete the works within a reasonable time. If the technical committee has given preference for the intermediate project it is because, among the three, it fulfills best all the conditions necessary to decide the present choice. This decision has been deemed the more rational because, between the two projects—the one which the committee has favored and the other with the lowest summit level—there is so complete an adjustment that a decision between the differences may be delayed for several years, and because the choice turned exclusively upon the doubt as to the time required to make the deeper central cut. This doubt will certainly be removed after three or four years' actual experience in working, and it will be then possible, without any mistake made or time wasted, to alter the decision according to circumstances. Thus the conditional character of this decision is apparent.

All the projects which have been examined by the technical committee have been studied and drawn by the technical corps of the company, under the constant supervision and with the active cooperation of the committee. All the discussions which have been set forth have been based upon data gathered by this corps and upon explanations which I supplied, based either on the original data dating from the origin of the studies or on the results which have been gradually collected by the investigations made under my direction. It follows that the work of the technical committee is, properly speaking, a work accomplished with the cooperation of the technical corps of the company. Therefore the synthetic report of the committee embodies, as to the general subject of construction of the canal and as to the conditions calling for the solution of the problem, as complete a summary as could be expected from the engineer in chief himself as to the studies made by the technical corps, as to their data, and as to the rational conclusions to be deduced. Personally, I may therefore dispense with another statement of the technical questions, referring, after my general remarks offered above, to the report of the technical committee, whose conclusions I consider as realizing the object which I would have sought in submitting to the company a general report on studies made by my department.

However, since the publication of the report of the technical committee, subsequent studies have shown the company and the committee itself the necessity of some modifications, especially as to the provisions concerning the profile type of the Culebra Cut. It is a necessary supplement to the said report to state and justify these modifications. On the other hand, the report of the committee does not enter in detail into the solutions of several special problems incident to the general construction of the canal or into their practical application. In this respect it is useful to complete the work of the committee. To meet this double requirement I have written the following technical notes as a natural sequel to the report of the technical committee, treating with more detail several special subjects which the committee has considered only from a general point of view. In the general problem of constructing the canal these subjects are considered special problems of great importance, whose solutions contribute to determine and to justify the general solution.

ORIGINAL PROJECT.

[illegible]

FIG. 1.

From a study of the practical construction of the cut and from a consideration of the logical plan to be adopted and of the order of the works I was convinced that the profile type adopted does not agree in the details with a progressive order which it seems natural to follow. The division in steps of 10 meters height, corresponding to the successive benches, is not quite judicious, because shovel work usually consists of cuts which are 4 meters deep, involving a step of 8 meters for two successive cuts. In practice the benches forming the successive steps of the cut should correspond exactly to the phases of excavation; therefore a vertical division at every 8 meters should be adopted instead of one at every 10 meters. With this end in view I have drawn for the 20.75-meter project a new profile type of the central cut which does not change perceptibly the cubic quantity to be extracted, and which has been approved by the technical committee at the meeting of June 12, 1899.

Likewise it has been found advisable to relocate slightly to the left the axis of the canal between P. K. 53 and 55, which will result indirectly in lengthening the radius of the curve of this portion of the canal from 2,500 to 3,000 meters. This slight modification of the line will permit any desired widening of the preparatory cunette between the above-mentioned points to be made on one side only; it will enable thereby a more advantageous distribution of the yards, while also avoiding quite important excavations on the side of the Cerro to the right of the preparatory cunette. Besides, this arrangement will allow all the excavations intended to be dumped at the Lirio to be transported without crossing the cut itself.

NEW PROFILE.

The new profile is represented by the following sketch. The section below water remains like that in the original profile. Above, the slopes have 5-meter benches every 8 meters; the slopes between two successive benches are regulated at 45° in ordinary soil, and at 2.50 of base to 8 of height in hard soil.

This profile applies to the entire central cut in the project of 20.75 meters elevation. The same profile would apply, in the 9.75 meter project, to the entire portion of this cut corresponding

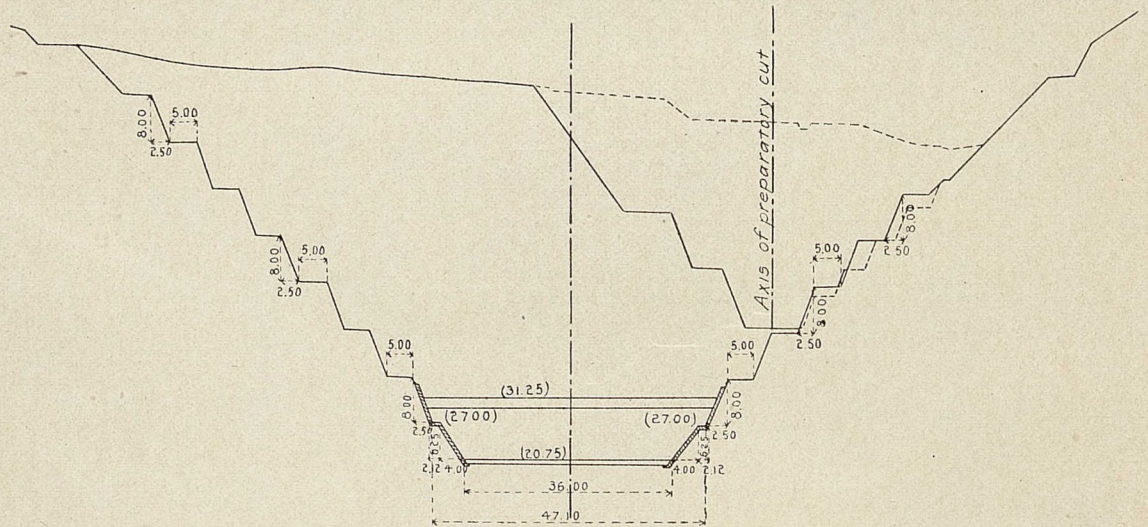


FIG. 2.

to the Emperador and to the comparatively low portions of the Culebra; but as to the portion of the last-named cut lying between P. K. 54.100 and 55.300, which is very deep in the said project, it has seemed to me possible and logical to make a change in the middle part (in altitude) of this profile, which would be very advantageous in case of a transition from one project to

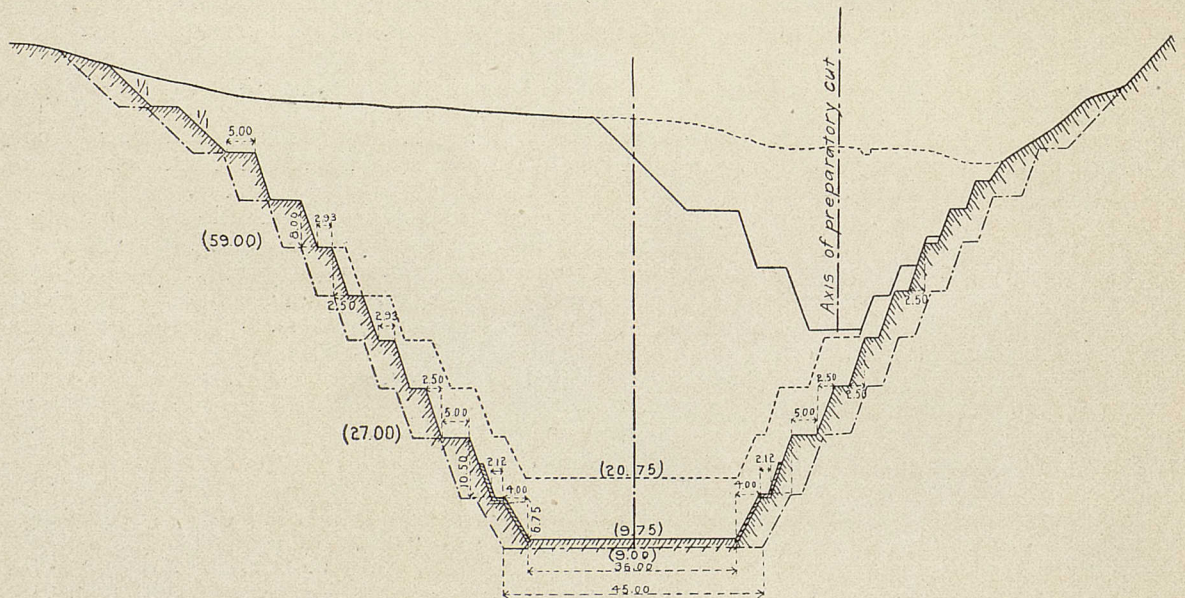


FIG. 3.

the other during the period of construction. This modification consists in reducing the width from 5 meters to 3 meters of four of the intermediate benches, corresponding to the hardest and most stable portion of the terrain. Thereby is gained a reduction of 16 meters on the total width of the cut at the level corresponding to the lowest contracted bench, the consequence being that, as regards the entire portion above this level, the profile of the cut in the 9.75-meter project

coincides with the profile in the 20.75-meter project above described. The excavations proposed in this portion would be therefore identical in the two projects, and the idea of deferring the decision between them until the work has advanced some years has a new justification.

The modification of the middle part of the profile type, which I have deemed useful, is justified by the following reasons when we consider the 9.75-meter project. The upper part of the profile corresponds either to ordinary soil or to moderately hard soil, so that this part requires the adoption in the two projects of a gentle profile with wide benches intended to receive any possible slides and to facilitate subsequent works of maintenance. In the lower part the profile of the surface of the bottom should be maintained as in the original, mainly for navigation considerations; in any event it is advisable to maintain the first 5-meter bench lying above water level, which will be used as a road and upon which tracks might be laid. But in the entire middle part (in height) corresponding to very stable material, and extremely important in relation to the 9.75-meter project, it is very rational to increase the average inclination of the slopes, and this is effected by contracting the benches. The same rule could apply to a certain extent to the profile in the 20.75-meter project, but it should be observed that the height of the cut, which would be affected by the modification, would be insignificant and the saving in excavation unimportant. It is preferable in this project to maintain uniformly the same width of benches, the advantage being that in the upper part of the cut the proposed excavations would coincide perfectly in the two projects. The only inconvenience, if ultimately the 20.75-meter project be adopted, will be an excavation on one side of the cut somewhat larger than was strictly necessary. The modification just indicated, relative to the profile applying to the 9.75-meter project, and illustrated above, was also approved by the technical committee at the meeting of June 12, 1899.

The estimates of volumes of the various excavations for the central cut proposed in the two projects have been revised by applying the approved profiles just described. The results are the following:

REVISED VOLUMES.

Project with bottom at elevation 20.75 meters.—For the entire central cut constituting the summit level, between P. K. 46.600 and 56.600, and including both the Emperador and the Culebra excavations: Total estimate of excavations, 22,750,000 cubic meters; portion lying between the origin of the Culebra proper at P. K. 53.600 and the extremity of the cut, 10,350,000 cubic meters.

Project with bottom elevated 9.75 meters.—For the entire central cut, between the same points as above, 31,350,000 cubic meters; the portion corresponding to the Culebra proper, 12,700,000 cubic meters.

Hence the differences in volumes between the two projects are:

Cubic meters.	8,600,000
For the entire cut.	.....
For the Culebra only.	2,350,000

These are perceptible reductions from the estimates indicated in the report of the technical committee (p. 38), especially as regards the estimates for the 9.75-meter project. This is due to the modification of the profile type and to the slight modification in the line of the axis of the canal, leaving intact the large slopes to the right of the preparatory cut.

I take this opportunity to point out an error which has slipped into the data on page 38 of the report of the technical committee; the portion of the line covering the estimates therein mentioned is stated to end at P. K. 55.500. This should read P. K. 56.600.

If we consider only the highest portion of the Culebra cut, which ends at P. K. 55.600, the estimated volumes will be as follows:

Cubic meters.	9,114,000
For the 20.75-meter project.	.....
For the 9.75-meter project.	11,117,000

The difference in volume between the two projects, as regards the Culebra, which had been estimated at about 4,000,000 cubic meters under the former profile, is only 2,350,000 cubic meters under the new conditions. The adopted modification therefore tends to bring much nearer together the two projects, in regard to the volume to be excavated in that portion; but the difference from the standpoint of delays involved in executing them must not be deemed to vary in a like proportion. The modification of the profile in the 9.75-meter project reduces the volume resulting therefrom in comparison with the original profile almost entirely from the excavations in the upper portion, where the work will prove comparatively easy and quick. The difference between the periods of time necessary to carry out the two projects will result almost exclusively from the deeper excavations and will not vary materially on account of the smaller volume applicable to the upper excavations.

The estimates stated above, as well as the prior estimates for the original profile types, have been made without taking into account the cubic quantity already taken out of the preparatory cunette. The omission of the reduction has been made intentionally, so as to offset any abnormal increase which is likely to augment materially the excavations resulting from the strict geometrical application of the regular profile; for the entire central cut this deduction is about 3,000,000 cubic meters. This quantity constitutes an elastic margin to meet unforeseen events, such as caving which must be removed, slopes to be made more gentle when deemed necessary in certain places, and above all increasing the width of portions bulging with respect to the regular profile, the real amount of which increase has not been definitely settled so far.

The adopted profile type provides an area of wet section of—

380 square meters for a minimum water level.

457 square meters for a maximum water level.

418.50 square meters on the average.

PROBABLE INCREASE OF THE WET SECTION.

The technical committee, in its earlier meetings, regarded the cross sections of the waterway provided as satisfactory for the navigation of most vessels. As to very large vessels, which will form always a small proportion of the total tonnage, the greatest inconvenience of these sections would be a reduction in speed through the central cut, for the same expenditure of power.

Nevertheless, several members of the committee have declared that it would be advantageous to increase to a certain extent the wet sections above mentioned, after considering the development in the size of midship cross section in large vessels and the utility of facilitating the navigation of the very largest vessels likely to pass through the canal in the future. In order to reach this result practically, it is necessary to increase the widths of the wet section at bottom as well as at water level, and to systematize the width of the entire cut from top to bottom by moving back together, parallel to themselves, the slopes of the adopted profile type. The necessary consequence would be a material increase in excavation at the central cut and especially at the Culebra proper. For example, as indicated in the dotted line of the previous drawing, by a widening of 10 meters in the wet section, the areas of that section would become—

470 square meters for a minimum water level.

562 square meters for a maximum water level.

516 square meters on the average.

The company and the technical committee have considered it interesting to study the material effects of a variation in the aforesaid projects, established on these bases. Moreover, in regard to the project providing the lowest summit level at elevation 9.75 meters with a maximum water level for Bohio Lake of 20.50 meters, whether it would be convenient to reduce this maximum level to 20 meters, as in the other project, and then lower the bottom to 9 meters.

Under these conditions, and with the definite adoption of the arrangements relative to the side walls of the profiles, the increased estimates for the excavations of the central cut as defined above would be as follows:

*For the first project (elevation, 20.75 meters).—*In round numbers, 3,000,000 cubic meters for the entire cut; 1,300,000 cubic meters for the Culebra only.

*For the second project (elevation, 9 meters, instead of 9.75 meters).—*In round numbers, 4,500,000 cubic meters for the entire cut; 1,800,000 cubic meters for the Culebra only.

In the second project it would also be necessary to widen the section as far as the end of the summit level at Pedro-Miguel, giving a total increase of excavation resulting from the widening of this project of 5,800,000 cubic meters.

These are important increases which would involve corresponding increases in expenses.

The company therefore would have to decide whether to accept this increase in expenses, which might reach about 20,000,000 francs for the 20.75-meter project and about 50,000,000 francs for the 9-meter project, in case all the benches of the lateral slopes were maintained at a width of 5 meters. The increase in the respective periods of construction might reach about fifteen months for the first project and thirty months for the second.

By holding the bottom elevation at 9.75 meters, with a profile of contracted intermediate benches, as stated above, the additional expense would be brought down to about 37,000,000 francs and the additional period of construction to about twenty months.

NOTE II.—*Water supply of the canal.*

The problem of water supply, so soon as it becomes a question of a lock canal, becomes one of the most important problems affecting the general realization of the undertaking, as it is connected with a question absolutely vital to its success. In order to solve this problem, it is necessary,

on the one hand, to study the demands for operating the canal and the means available to meet them; on the other hand, the methods to be adopted for surely and at any time utilizing these means in proportion to the requirements.

REQUIREMENTS.

In a special paper, in which General Abbot collaborated, I have made a thorough study of the supply of water necessary to operate the canal, adopting for the future the most extreme hypotheses as to the anticipated traffic. I shall confine myself here to giving a summary, and the results of this study. In the first place, the operation of the canal requires the volume necessary to compensate the consumption due to the lockages of vessels passing the locks. As appears from the special paper, this volume is equivalent to a continuous discharge of 10 cubic meters per second, in case of a yearly traffic of 10,000,000 net tons, and of 24 cubic meters in case of a yearly traffic of 23,000,000 tons.^a

This estimate supposes that, neither in the administration nor in the operation, will there be practiced any of the customary devices for reducing the consumption of water. Next come the losses due to unavoidable defects in mechanical arrangements, such as leakages at gates. They are liberally estimated at 3 cubic meters per second. Losses due to natural causes, such as evaporation, infiltrations, etc., are estimated liberally at 5 cubic meters per second. Finally is added for consumption due to unforeseen causes a volume of 2 cubic meters per second. The total requirements for the supply of water to the canal, largely estimated, represent a continuous discharge per second of—

20 cubic meters in case of a traffic of 10,000,000 tons.

34 cubic meters in case of a traffic of 23,000,000 tons.

Outside of the requirements for feeding the canal, and which must necessarily be met by an appropriate supply of water, we have to consider the mechanical power required at the locks and at the harbors and for lighting the canal and its accessories. Strictly speaking, this power may be realized by industrial means without resorting to water, but economically and from a practical standpoint it is advantageous, if possible, to use water as the primary source of energy. At the two dams at Alhajuela and at Bohio, the construction of which is demanded for other reasons, there are important falls capable of generating great power at little cost, which can then be distributed by electric means to any desired point. The volume of water considered desirable for this purpose is 7 cubic meters per second. This volume, successively passing over the two falls at Alhajuela and at Bohio, which represent together at least 46 meters of height, will supply a total of 4,300 horsepower at the starting points, and with a reduction of 50 per cent will reach the places of consumption. This is a considerable power, which exceeds certainly all the normal requirements, however large. As a surplus, however, for exceptional cases, and in order to have a very ample supply, justified by the resources available, as will be seen hereafter, there has been made a further addition of 8 cubic meters per second. This addition will either allow new power works for industrial use or will serve to meet new requirements created by accidental circumstances exceeding all prevision, but for which provision has been made.

If we add the 15 cubic meters per second, thus provided for special requirements, to the volume above given for feeding the canal, it will be seen that the volume of water necessary to meet all the requirements estimated in the largest sense will be as follows:

35 cubic meters for a yearly traffic of 10,000,000 tons.

49 cubic meters for a yearly traffic of 23,000,000 tons.

The last number represents the maximum estimate for the future, and will hardly ever be reached, since a traffic of 23,000,000 tons represents about thrice that of the Suez Canal at present.

We must not lose sight of the fact that in the aforesaid volumes of 35 and 49 cubic meters per second the 15 cubic meters intended for special requirements must pass directly from Alhajuela into the lower lake, and therefore will not follow the feeder. The volumes which this feeder must carry will vary, according to cases, between 20 cubic meters and 34 cubic meters per second. Its arrangements have been designed to meet these requirements in a manner entirely satisfactory.

RESOURCES.

The resources to meet the requirements above estimated consist mainly in the contributions of the Chagres itself, and upon these contributions are based the comparative estimates of means available to meet the demands. It will be useful, however, to point out that several other streams exist with quite important discharges during the rainy season, and which are easily capable of

^a This estimate takes into account the final decision of the company to give both chambers of the twin locks the same width of 25 meters.

contributing to the supply of the summit level. For example, we find in the very region bordering this level on the one side the Rio Obispo and its tributaries, chief among which are the Lirio and the Camacho, and on the other the Rio Grande. These two streams will flow directly into the summit level, and naturally their contributions will assist. During the rainy season—that is, for seven or eight months in the year—these contributions are quite important, the accumulated discharges of these rivers representing during the rainy season a total of not less than 5 cubic meters per second. During the dry season their discharges are insignificant and not worthy of mention; but, since the Chagres does not supply all the necessary water during the dry season, as will be seen below, and since a surplus must be accumulated by storing the excess of the rainy season, the contributions of the secondary rivers during that period will reduce the volume to be demanded from the Chagres, and thus will increase by that amount the available surplus. The same is true for several secondary streams which cross the line of the feeder and which can contribute to supply it during the rainy season. However, in what follows no account is taken of these accessory means, yet it is of interest to remember the fact, which strengthens the conclusion reached, that the available supply is estimated at a minimum, while the requirements are estimated at a maximum.

The special paper relative to the regimen of the Chagres, based on numerous and certain data, exhibits the average discharges of the Chagres during the various months of the year passing at Alhajuela, where the supply is stored. It follows, if we consider the two years of minimum contributions of the Chagres, that its average annual discharge at Alhajuela amounts to 58 cubic meters per second. In other words, with requirements estimated under conditions certainly exaggerated and upon the hypothesis of a yearly traffic of 23,000,000 tons in a period of unusually low discharges, there will still remain a margin in excess amounting to 9 cubic meters per second during the whole year, and this without taking into consideration the contribution of the secondary streams referred to above.

The special paper on the regimen of the Chagres makes known that its average discharge at Alhajuela during the months of February, March, and April, in the most unfavorable years, may be set down at 18 cubic meters per second, which, as a measure of precaution, has been reduced to 16 cubic meters in the estimate. During the remainder of the year it exceeds the volume required for maximum needs. We have seen that on the basis of a yearly traffic of 10,000,000 tons the deficit in the contributions of the river during the dry season would be $35 - 16 = 19$ cubic meters per second, including the 15 cubic meters intended to create motive power or to meet unforeseen requirements. On the basis of a traffic of 23,000,000 tons, the deficit would be $49 - 16 = 33$ cubic meters per second. Therefore it will be necessary to provide a surplus to meet these deficits, which is one of the main objects of the reservoir at Alhajuela. It is necessary also that the surplus be accumulated before the rainy season; that is, by the end of December. The total volume under the first hypothesis as to traffic would be 147 millions of cubic meters, and under the second hypothesis 256 millions of cubic meters. The study on the regimen of the Chagres shows that in years when discharges are smallest its average discharge for the last two months of the year is 91 cubic meters per second. Deducting from this discharge the 35 or 49 cubic meters required for the regular operation of the canal, there remains available 56 or 43 cubic meters per second, which, during the interval of the said two months, will supply a total volume of 295,000,000 cubic meters in the former case and of 227,000,000 in the latter. The accumulation of the surplus can then be made simply from the excess of these two months (and even from the month of December alone in the first case). The deficiency of 29,000,000 cubic meters which might occur in the second case should be supplied either by storage dating from the end of October or in the early part of January.

ARRANGEMENTS FOR REGULATING AND UTILIZING THE SUPPLY.

In the intermediate project the arrangements at the Alhajuela dam are so established as to retain a total reserve of 270 millions of cubic meters—170 millions for the low-water supply and 100 millions to hold back part of the injurious excess in floods. The 170 millions of so-called useful reserves correspond to a probable yearly traffic of 14 millions of tons. Should the total traffic exceed this amount, and should the average tonnage not exceed 3,000 tons for a single lockage (the figures on which the lockage estimate is based), the 170 millions of cubic meters for reserves, including power and unforeseen requirements, should be increased. To accomplish this end, it would be necessary either to use part of the capacity intended to store the floods, or to raise the dam, or to provide an additional surplus elsewhere. It is essential to note that the means available allow a large margin in excess of the requirements, even if we consider the most unfavorable hypotheses.

The utilization of the resources necessary for the operation of the canal, in projects where the summit level is above that of Bohio Lake, requires the construction of a feeder between that level and the Alhajuela dam, where the water supply would be stored. The project for this

feeder has been fully set forth in the file of descriptive drawings, and I shall not treat it again here. I shall recall only that its provisions are such as to insure at the outset a discharge from the feeder of 25 cubic meters per second, and in the future, if necessary, a discharge exceeding 35 cubic meters per second: For that it will suffice to increase by half a meter the water level in the open section of the feeder and to lay a fourth pipe in places where a reversed syphon had to be adopted. This will involve no difficulty. The discharge of 35 cubic meters per second will fulfill the most extreme conditions; for we have seen that by omitting the 7 cubic meters per second intended as motive power and the 8 cubic meters for exceptional contingencies—that is, the 15 cubic meters which are not carried by the feeder—there remain only 34 cubic meters per second to represent the maximum volume which can be necessary for supplying the canal even in so distant a future that it is difficult to anticipate it.

NOTE III.—*Practical statement of measures adopted for storing part of the floods of the Chagres and the regulation of its flow in the region traversed by the canal.*

GENERAL CONDITIONS OF THE PROBLEM. PRINCIPLES OF THE SOLUTION ADOPTED.

The problem of regulating and of moderating the floods of the Chagres, or of controlling it, is only second in importance to the problem of supplying water. Its solution concerns the regular operation of the canal. The general method adopted for this solution, and the principles forming its basis, have been set forth in the report of the technical committee; I shall only briefly recapitulate them here.

The canal line, starting at Colon, meets the valley proper of the Chagres at P. K. 10. So far it has crossed a region usually of low and swampy lands, but with a few moderate elevations. It is called the Mindi swamps, and is little exposed to the floods of the Chagres. The valley near the mouth of this river follows a direction almost at right angles to the canal line. From P. K. 10 to P. K. 45 the latter follows directly the valley of the Chagres, even cutting a number of times the course of this river, which contains many bends. In this region the width of the valley varies greatly. Quite wide at first, as far as the vicinity of P. K. 24, at Bohio Soldado, it contracts at this point between two rocky bluffs; then it widens greatly so as to form the vast plain of Tavernilla, which is several kilometers in width. Farther on, beginning at P. K. 34 of the canal, the valley narrows down again and remains so, except for some local variations and windings, as far as P. K. 45 of the canal, near Matachin, where is the point of junction of a tributary, the Rio Obispo. From this point on, the canal line entirely leaves the valley of the Chagres, which by a sharp bend at right angles ascends northeastward, while the canal follows its course southeastward. Beyond this point the question of the Chagres does not interest the canal. Thereby it will be seen that it is in the middle region of the Chagres, lying between P. K. 10 and P. K. 45, that the problem of the floods of the Chagres and their possible action upon the canal possess their dominating importance.

The fundamental idea of the solution adopted to control the regimen of the Chagres in time of large floods and to protect the canal against its ravages is simple. It consists in transforming, by means of a dam at a suitable place, the middle part of the valley just referred to into a lake, in which the waters of the Chagres will spread without causing any sensible current, and which may be made navigable without danger or difficulty. The only point sufficiently favorable to the construction of a dam is the natural contraction referred to above, at P. K. 24. Consequently that part of the valley lying between P. K. 10 and P. K. 24 is not turned into a lake, and in this district artificial channels collateral to the canal must be provided to convey the waters of the Chagres after issuing from the lake. The very creation of this lake allows part of the volume to be held back therein in time of highest floods, to be discharged later, and thus will reduce to a safe volume the flow from the lake into the special diversions down the river. Such is, in its simplest form, the principle of the method to solve the problem of the control of the Chagres. It may be said that this method is borrowed from nature itself, which supplies many and important examples in the lakes of mountainous regions with their torrential rivers. No objection can be raised against its efficacy; the only objection would be as to the practicability of constructing the dam, which is the key to the problem; and the studies and discussions of the project for this work have shown that there is here no valid objection.

The application of the method must be supplemented by a preliminary step which, however secondary in character, is nevertheless necessary. The central lake, which has just been referred to, would be quite narrow and winding for some distance. On account of the resulting currents it would be disadvantageous to admit into these parts of the lake the entire discharge of the Chagres in time of maximum flow during a great flood; therefore it has been deemed necessary to hold back part of it in a first reservoir situated in the upper valley of the Chagres. This

reservoir is formed by the proposed dam at Alhajuela, whose primary purpose, as I have said in Note II, is to store the reserves intended to feed the canal, but with an appropriate height of dam to afford sufficient capacity to hold back part of an excessive flood.

REGIMEN OF THE CHAGRES.

In the special paper, in which General Abbot collaborated, all the conditions relative to the regimen of the Chagres in time of floods have been thoroughly elucidated, based upon very complete data covering a great number of years. I shall not restate these conditions again, but will confine myself to the principal facts and the resulting conclusions bearing upon the special problem now under consideration. (See the annexed Note A, page 133, summing up the reasons for these conclusions.)

GENERAL CONDITIONS FOR STORAGE.

It has been established that the highest flood to be anticipated will discharge at Bohio a maximum of 3,170 cubic meters per second, and an average of 2,640 cubic meters per second during the forty-eight-hour period of its maximum flow (between an initial discharge of 1,200 cubic meters and a final discharge of 1,200 cubic meters). If, therefore, during this period an average discharge (uniform or varied) of 1,200 cubic meters per second be allowed to pass freely at the spillways at Bohio, there will remain an excess of 1,440 cubic meters per second to be held back momentarily, and to be discharged later when the natural contribution of the flood has fallen below 1,200 cubic meters per second; thus the total volume to withhold is about 250 millions of cubic meters. However, as has been said above, it would be imprudent to admit into Bohio Lake the entire contribution of the flood during the period of highest flow; and it has been recognized as expedient to retain in the upper lake at least an average of 600 cubic meters per second, which for the total period represents about 100 millions of cubic meters. It follows that the 250 millions of cubic meters to be stored are distributed, 150 millions in Lake Bohio and 100 millions in the upper reservoir. A modification of this distribution, however, has been adopted for the project in which Lake Bohio would constitute the summit level. It is very advantageous to limit as much as possible the extent of the oscillations in the level of this lake, and with this object in view the part which it is to store is reduced to 100 millions of cubic meters, whereas the other is increased to 150 millions.

The 100 millions of cubic meters which form the reserve of Lake Bohio in this case correspond to a height of water of 1.75 meters lying between the 18.75-meter elevation, which would be the minimum level of this lake, and the 20.50-meter elevation, which would represent the maximum, very seldom reached. This elevation has been adopted instead of the 20-meter elevation, which is the limit in the prior project, in order not to deepen any more the excavation in the large cut. Consequently, in cases very rare and of short duration, the Bohio locks momentarily may have their lift increased to 10.25 meters, which can not cause any inconvenience. In order to obviate this slight increase it would suffice to reduce the maximum water level to 20 meters and the bottom to 9.25 meters in this level, but this would result in important additional excavations. This level has been adopted in the variant with a bottom elevation at 9 meters where the width at the bottom in the summit level would be 45 meters.

These data relative to the solution of the problem in question and the conditions to be fulfilled have been accepted after discussion at the meetings of the technical committee and in its report. I shall not dwell thereon any longer, but I have still to indicate the practical method which will realize these conditions.

PRACTICAL METHOD OF APPLICATION.

The following is the end to be attained in the operation, natural or under orders, of the works at the two stations of Alhajuela and of Bohio:

Suppose a flood, the intensity of which can not be anticipated but which is supposed to equal in degree the greatest flood known in the past, that of 1879 (such a flood is possible only at the end of the year, the latter part of November, December, or the beginning of January). This flood, during forty-eight hours of its largest flow, may discharge at Bohio from 1,200 cubic meters per second to a maximum of 3,170 cubic meters, falling again to 1,200 cubic meters, giving an average volume of 2,640 cubic meters during the entire time referred to. Such arrangements must be made either through the automatic operation of the works, or through the agency of men, that (1) the discharge through the outlet of Lake Bohio does not exceed 1,200 cubic meters per second (for the sake of simplicity, I assume that the two outlets of the lake form only one); (2) the average total flow into the lake is reduced to about 2,000 cubic meters per second instead of 2,640; (3) an average of 600 cubic meters per second of the total contribution is held back in the upper reservoir during the entire time referred to. It must follow from

these three conditions that out of the total contribution of the flood during its largest flow (forty-eight hours), there will be stored 250 millions of cubic meters, of which 100 millions will remain in the upper reservoir and 150 millions in the lower reservoir. This exactly accomplishes our purpose. In order to fulfill these conditions how shall the material operations be regulated? The operations must be begun at the moment when the flood is announced if we assume that the spillway constituting the Bohio outlet is provided with a system of adjustable weirs wherewith to regulate its discharge artificially, as is provided in the project of the company. (We shall see later what might happen should such a waste weir not be provided.)

The regular level of the lake except in the dry season is fixed at 17 meters. During the dry season it may decline gradually to 16 meters on account of losses through evaporation and infiltrations, but without any inconvenience, since the bottom of the navigable channel of this lake is at elevation 7 meters. When a flood occurs near the end of the year, that is, a flood presumably very intense, the sluices will be so operated as to discharge such a volume integrally through their gates that the level of the lake shall not fall below 17 meters, or rise materially above it, so long as the entire discharge of the waste weir has not attained 1,200 cubic meters per second. The sill of this waste weir is set at elevation 14 meters, and the aggregate length of outlet of the sluices is arranged to discharge, when entirely open, the 1,200 cubic meters per second between elevations 14 meters and 17 meters. Therefore, we shall be warned when the discharge of the flood at this point has reached 1,200 cubic meters per second, and at this moment storing operations must begin to regulate the distribution between the two reservoirs, still maintaining the discharge of the outlet at 1,200 cubic meters per second. This last condition admits of ready realization. It is easy to determine in advance, and to indicate in precise instructions, what lengths of free channel the sluices must have, that is, how many sluices must be opened, at the various successive levels of the lake, between the original elevation of 17 meters and the maximum elevation of 20 meters, which latter must not be exceeded, in order to always insure a discharge of 1,200 cubic meters per second. At this limit, all the sluices which are 3 meters high will be closed and the 1,200 cubic meters will be flowing over the tops of their gates.

Practical arrangements for distribution between the two reservoirs.—In order to insure a practical distribution between the two reservoirs of the volume to be held back in the proportions of 100 and 150 the engineer stationed at Alhajuela must be forewarned of the limiting discharge which he is to let through his waste weir at the time when he is to begin storing, which time will be notified to him by Bohio, being the moment when the discharge of the flood at that point has reached 1,200 cubic meters. The problem thus laid down would be very easy to solve if, during the forty-eight hours referred to, the flood had a uniform discharge equal to the average of 2,640 cubic meters, instead of a varying discharge from 1,200 cubic meters to 3,170 cubic meters, declining back to 1,200 cubic meters and averaging 2,640 cubic meters in round numbers. The special paper on the regimen of the Chagres informs us, indeed, that the contribution at the time of largest flow of the flood, coming from the basin above Alhajuela, is about half of the total discharge at Bohio, so that a discharge of 2,640 cubic meters at that point would correspond to a discharge of about 1,300 cubic meters at Alhajuela.

The other requirement consists in letting into Lake Bohio only about 2,000 cubic meters per second; therefore 600 cubic meters should be held back from the contribution of the basin above Alhajuela, and only 700 cubic meters per second should be allowed to escape through the regulating waste weir at Alhajuela. Finally, if, according to our hypothesis, we substitute a flood of uniform average discharge for the real flood of varying discharge, it will suffice to order Alhajuela to allow to pass through its waste weir all that comes along up to 700 cubic meters per second, and when the contribution exceeds this volume, to hold back all the excess, storing it in the space reserved for that purpose. It would suffice, then, to draw a regulation defining the number of sluices to be gradually closed in proportion as the level of the lake should rise.

The solution of the problem would become much more complicated if a rigorous solution be sought for the case of a real flood with its varying discharges instead of an equivalent averaged flood. This would require a precise knowledge of the curve of discharge in the former, but for practical purposes it will be sufficient to proceed approximately, as follows:

Suppose $A B C D \dots$ (fig. 4) to be the curve of the flood at Bohio during the period when, from a discharge of 1,200 cubic meters it rises to 3,170 cubic meters and declines back to 1,200 cubic meters, the area between the horizontal $A N$ corresponding to the discharge of 1,200 cubic meters, and the curve $A B C D \dots$ represents the 250 millions of cubic meters to be held back. Suppose $B'b = 2/5 B'B$, $C'c = 2/5 C'C$, and let us draw the curve $A b c d$; the area between the horizontal $A N$ and this curve will represent 100 millions of cubic meters, which is the part to be held back at Alhajuela.

This done, let us draw the curve (fig. 5) of the flood at Alhajuela during the same period. For this, let us assume, according to the special paper on the regimen of the Chagres, that the discharge at Alhajuela during the forty-eight hours of the maximum flow of a great flood is

uniformly half of the discharge at Bohio. To obtain the curve, reduce by half all the ordinates of the curve (fig. 4). At B'C'D' let us draw ordinates equal to B'b, C'c, D'd, of figure 4; the shaded area of figure 5 will represent the total volume to be held back at Alhajuela, and the

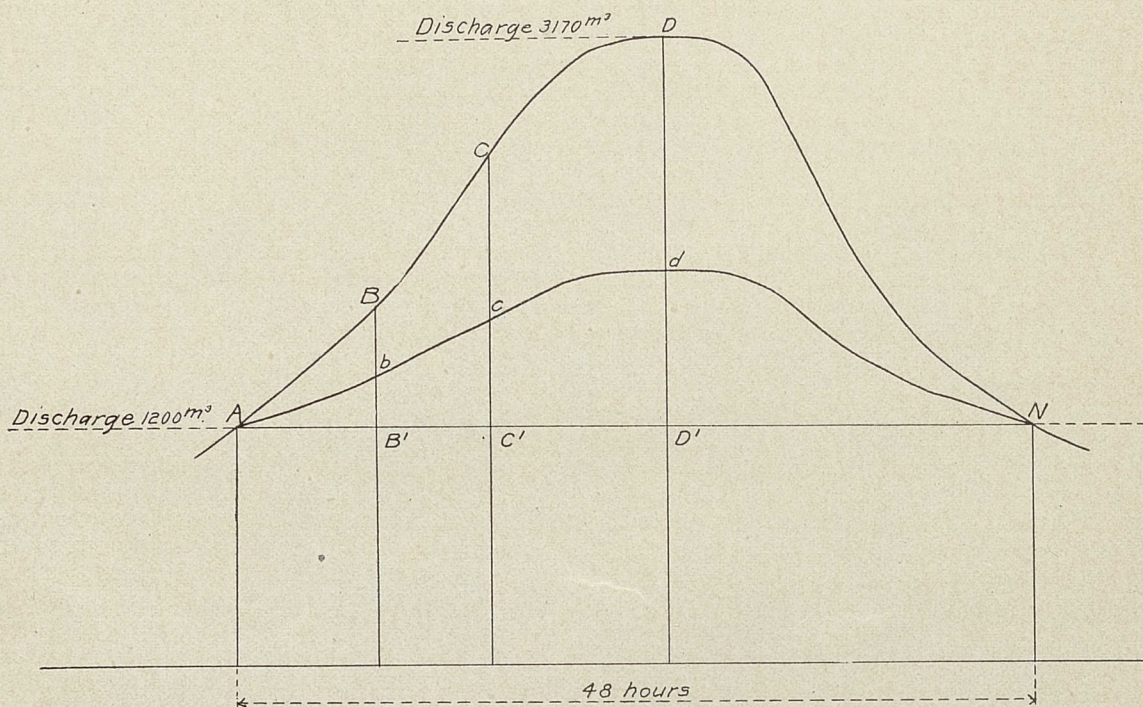


FIG. 4.

area lying between the two curves will represent the volume that should be allowed to pass there. Now, it is easy to see that the differential ordinates $b\beta$, $c\gamma$, $d\delta$. . . , differ very little one from another. For instance, take the ordinate of the culminating point $d\delta$, we have:

$$d\delta = D'\delta - D'd$$

Now, $D'\delta = \frac{3,170}{2} = 1,585$, $D'd = \frac{2}{5}D'D = \frac{2}{5}(3,170 - 1,200) = 788$, hence, $d\delta = 1,585 - 788 = 797$, say 800.

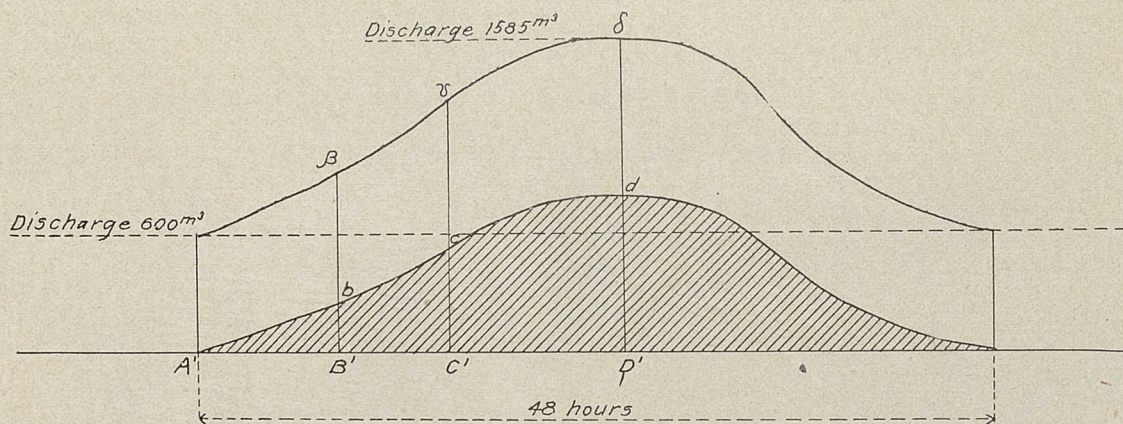


FIG. 5.

The varying discharge which should be allowed to pass at Alhajuela during the forty-eight hours considered should increase from 600 cubic meters to 800 cubic meters and then decline back to 600 cubic meters. It would not be practical to attempt to regulate the discharge of the

waste weir so as to make it vary from the time when the flood brings 600 cubic meters to the time when it declines back to this volume; but, on the other hand, it is simple to regulate the flow to a uniform discharge all the while the contribution would be superior to this volume.

Theoretically, the entire flow should be allowed to pass at Alhajuela up to the moment when the discharge has reached 600 cubic meters, then allow a flow increasing from 600 to 800 cubic meters and decreasing afterwards from 800 to 600 cubic meters, according to a law which could only be approximately defined, and finally allow all to pass after the flood has returned to a discharge of 600 cubic meters. Instead of this, another rule might be given, to let all pass up to a volume of 700 cubic meters, the average between 600 and 800 cubic meters, and to limit to this uniform volume the discharge through the waste weir until the flood declines to 700 cubic meters, then to let pass again the entire flow. In this way a little too much will be let pass at the two extreme moments of the period (which will, however, be somewhat cut short) and a little too much will be held back toward the middle of the time. There will thus be a compensation, and the method will prove quite sufficient in practice.

It will be seen readily that a like method can be applied in case the volume to be stored at Alhajuela were 150 millions of cubic meters, and that at Bohio 100 millions—that is to say, in the project where Lake Bohio constitutes the summit level. In this case, if we refer to figures 4 and

5 above, $D'd$ is equal to $\frac{3}{5}$ of $D'D$, or 1,182, and $d\delta$ becomes $1,585 - 1,182 = 403$, say 400. The volume which would be left at Alhajuela during the time referred to should then decrease first from 600 to 400 cubic meters, and then increase from 400 to 600 cubic meters. Instead of this, the average, or 500 cubic meters, might be taken as the uniform discharge, and all the excess be stopped.

For the sake of simplicity, in what precedes the development of the maximum flows of the flood has been considered as simultaneous at the two stations of Alhajuela and of Bohio, which are about 45 kilometers apart, according to the course of the river. Evidently this can not happen, and the flood wave arrives at Bohio with a material delay after it passed Alhajuela; but this does not affect the basis of the reasoning or the deductions to be drawn. The operations required at Alhajuela will remain the same; and it is easy to see that their results will also remain the same, and will be transferred to Bohio simply with a delay due to the passage of the flood between the two points, without otherwise changing the phenomena at this point under the hypothesis adopted.

MECHANICAL ARRANGEMENTS PROVIDED FOR INSURING THE OPERATIONS.

The mechanical arrangements for realizing the operations just indicated are simple. They consist in providing the waste weir at Alhajuela with a system of sluices, which, when opened more or less, regulate the discharge according to the volume desired. The directions for closing or opening the sluices will be drawn up readily, so as to discharge a given volume, according to the different successive levels of the lake during the flood. Considering the projects where the reservoir of Alhajuela must withhold only 100 millions of cubic meters from the floods, the sluices are provided with 48 meters of free outlet; the sluices are each 6 meters wide and 4 meters high; when lowered, their top is at the elevation of 65 meters, which is the starting point for storing the floods, and their sill is at 61 meters elevation. In case a flood occurs near the end of the year (which is always supposed to call for the working of the storing arrangements), the lake may be already filled to the altitude of 65 from the storage of the so-called useful reserves. If it be not entirely filled, the first contribution of the flood will be made use of to fill it to that level. This done, a certain number of sluices will be successively opened, so as to let pass the entire flow, without lowering the stand of the lake below the 65-meter level, until the discharge has reached 700 cubic meters per second. When this limit has been reached all the sluices will have been raised 4 meters. Indeed, it will easily be verified by the waste-weir formula, that a passageway 48 meters long with 4 meters head on the crest will discharge about 700 cubic meters per second. At this moment, if the flood continues to increase, the storage should begin. In order to attain this object systematically, the sluices must be closed successively, so as to maintain the discharge at 700 cubic meters—following the directions drawn up in advance, indicating the successive levels assumed by the lake in proportion as it fills up. When 100 millions of cubic meters have been stored, the lake will have reached its full elevation of 68 meters. Then there will be entirely lowered a certain number of sluice gates over which a flow 3 meters deep will pass; there will be also a certain number of open sluices with a full opening and a head 7 meters high; the total of both discharges will be 700 cubic meters per second. If x and y represent the aforesaid two linear outlets, respectively, aggregating 48 meters in length, it may readily be computed that $x=30$ meters and $y=18$ meters.

All the necessary calculations are simple, and will be made beforehand, in order to frame a precise and simple rule which the engineer in charge will merely have to follow, and on which

the successive levels of the lake read on the gauge will indicate exactly the number of sluices which are to be raised entirely or lowered entirely while the lake oscillates between elevations 65 meters and 68 meters. As to the fluctuations below 65, they will be due to the consumption requirements of the operation of the canal; the operations of the sluices which refer to them will be regulated by special instructions based on these requirements as experience reveals them. The system of sluices thus far projected is that of the Stoney counterpoised weir, in use on the Manchester Canal. They are thoroughly proof against leakage and they work well. Still it is possible that at the date of construction there may be a more advantageous system.

The problem of regulating the discharge at the Bohio waste weirs is solved in the same way, as has been said above; the system of sluices provided is the same, but the gates are each only 3 meters high, and the length of the two free outlets together is limited to 130 meters, in view to a maximum discharge of 1,200 cubic meters per second.

We have just seen that the solution adopted for regulating the floods of the Chagres provides, in case of the largest flood anticipated, for withholding momentarily 250 millions of cubic meters, either 100 millions or 150 millions of which will be the share of the upper reservoir, according to the project adopted. The primary condition is that the contributions of the flood at that point, as soon as storing is resorted to, shall be at least equal to the volume assigned to this upper reservoir. From the study of the regimen of the floods of the Chagres we know that, in large floods, the discharge at Alhajuela is about half of that passing at Bohio. The total volume flowing past Bohio in a flood like that of 1879, from the moment when its discharge reaches 1,200 cubic meters, is, as we know, about 457 millions of cubic meters; in this total the contribution of the basin above Alhajuela is about 230 millions of cubic meters; far superior, therefore, to the reserve volume attributed to the upper reservoir.

CASE OF A FLOOD EXCEEDING THE ESTIMATE ON WHICH THE PROJECT IS BASED.

The arrangements adopted are based on the idea that the volume of 457 millions of cubic meters is the maximum flood contribution at Bohio during the time when the discharge exceeds 1,200 cubic meters per second. The data and the deductions used in establishing this volume authorize us to believe that it was not exceeded or even reached in the flood of 1879, the largest of which we have knowledge; but it may always be objected that a greater flood may occur at some time. What, then, will take place with the arrangements adopted? The only thing to happen is that, when the Bohio reservoir is filled to the limit provided—that is, to the elevation of 20 meters—the contribution of the flood, instead of falling to 1,200 cubic meters per second at that moment, as has been expected, would remain more or less superior to that volume. To keep the level of the lake from being superelevated would then require opening more or less the sluice gates of the waste weirs, thus maintaining this level by increasing the discharge of the outlet. The only possible consequence to be guarded against would be the increase of the discharge in the diversion channels of the lower river beyond 1,200 cubic meters, which might result in danger to them and to the canal. It is understood that the 1,200 cubic meters in question are divided into 500 cubic meters in the diversion to the left of the canal, and 700 cubic meters in the diversion to the right. The left diversion, for almost its entire length, is an artificial canal dug through grounds generally quite unstable and skirting the railroad for a long distance. It enters the sea in the vicinity of Colon. The greater part has already been excavated by the old company, and it is only necessary to widen it in order to enable it to carry off 500 cubic meters per second.

It would not be prudent to increase its discharge materially beyond this already quite large volume. It would be imprudent above all to expose it to the hazards of an undetermined discharge and of a flood. In any event, I think it is essential to be sure that its contemplated maximum discharge shall not be exceeded, and this result can always be obtained by means of the regulating sluices with which its waste weir would be provided, no matter to what level the lake might rise. As to the right diversion, the conditions are very different. There the outlet of the lake is very distant from the canal; its flow will first enter a wide swamp (the Peña Blanca swamp), thence it will pass to another much larger (the Agua Clara swamp), crossing an intervening ridge. Thereafter, the flow will follow the bed of the Chagres, which will be its natural outlet, except for a short distance near Gatun. Under such conditions there is no reason to apprehend danger even from a considerable increase of discharge in that diversion over the 700 cubic meters, which is the maximum volume assigned to it. It will suffice to protect the canal against a possible flood in this diversion by means of a lateral embankment a few meters high wherever necessary, and this has been projected. Therefore I think no difficulty will arise if the right diversion from Lake Bohio should ever carry from 500 to 600 cubic meters beyond its maximum, and this would enable us to face the improbable circumstance of a flood exceeding that of 1879.

DISCUSSION OF THE HYPOTHESIS OF WASTE WEIRS WITHOUT SLUICES.

In reference to the discharges through the outlets of Lake Bohio and into the diversion channels prolonging them, a question arises which is of very considerable interest. In the arrangements projected, the waste weirs governing the two outlets are provided with sluices which regulate the discharge of each of them to a limited volume, which can remain invariable in spite of fluctuations in the level of the lake. This arrangement will regulate, at 1,200 cubic meters per second, the total discharge of the waste weirs so soon as the contribution of the flood has reached this volume, and will then hold it at that volume until the lake has reached its maximum level. In such a regulating apparatus there are evidently several advantages, but it may be objected that at any moment it may fail to work well, or may be wrongly operated, like any other mechanical installation in the hands of men. It may be asked, then, whether equivalent results could not be obtained with waste weirs without sluices, through which the flow would be governed merely by the action of natural laws. For reasons above stated it seems to me indispensable to provide the left waste weir with sluices, as in the project, since it regulates a diversion where it is necessary to control the discharge. As to the right waste weir, it might be constructed without sluices, regulating its sill at 17 meters elevation, which is the regular level of the lake. It is easy to be seen, a priori, that by giving this waste weir a proper length the result may be obtained that as the lake rises to 20 meters elevation, in proportion as the flood develops, part of its contribution will be stored, while all the rest is discharged, and this without this level being exceeded. But the essential difference between this system and that of a waste weir with regulating sluices is: First, That the discharge of the waste weir will go on always increasing from zero up to a quantity likely to exceed 700 cubic meters per second, instead of remaining uniformly at 700 cubic meters; second, that the rise of the lake beyond the 17-meter elevation, the starting point for storage, will begin before the contribution of the flood has reached a discharge of 1,200 cubic meters, and that consequently part of the reserved space will be filled prematurely with a volume which escaped in the other system.

It is possible to reduce to figures the conditions of discharge just indicated in order to find the required length of such a waste weir. The formula are known, and, although complicated, admit of a scientific solution. Under the admitted conditions in regard to the increase of the flood, under which a volume of 100 millions of cubic meters should be held back in the upper reservoir, such a waste weir must have a length of free outlet of 147 meters. Its length in the system with sluices is only 76 meters. The widths of the discharging channel below the waste weir would be, of course, regulated in proportion. The maximum discharge, thrown into the diversion channel, might reach 1,353 cubic meters per second instead of 700 cubic meters, as in the first system. The total cost of the works in the two systems would be about the same, owing to the fact that near the edge of the projected lake, in the vicinity of the waste weir, the level of the natural ground is higher than the elevation to which the waste weir must be cut in either system. A channel leading to the waste weir must then be opened for the waters within the lake. In the first system this channel must be lowered to elevation 14 meters, whereas in the second the 17-meter elevation will suffice. The saving resulting therefrom compensates the increases in cost resulting from lengthening the waste weir and from widening the channel which extends it. The second system has the advantage of not requiring the installation of mechanical apparatus at a waste weir situated far from the canal and from the Bohio station, where will be concentrated the working staff for that point. This advantage seems to me important enough to cause the adoption of this system, despite the material increase of the discharge in the diversion channel on this bank of the canal. The topography of the region does not present any serious difficulties.

NOTE A.—*Annexed to Note III.*

Examination of plausible hypotheses to deduce from the known curve of the flood of 1893 the probable curve of the flood of 1879, during the time when the discharge exceeded 1,200 cubic meters per second.

From the moment when the discharge reached 1,200 cubic meters per second up to the time when it returned to this volume, the flood of 1893 may be illustrated very nearly by a segment of a trapezoid, as in figure 6, the stand covering a period of eight hours, with a discharge of 1,430 cubic meters.

It is important to understand the probable transformation of the line a b c d, when the maximum volume of 1,430 cubic meters increases to 3,170 cubic meters with an elevation of 12 meters instead of 8.65 meters. There is no reason for being concerned with what happens before the discharge has reached 1,200 cubic meters or after it has returned to that volume, since the only thing to do then is to allow it to pass freely.

Several more or less plausible hypotheses may be made in order to arrive at a logical solution of the transformation of the line, and we should seek to arrive at a result certainly larger than the real volume, so far as total discharge is concerned, but without falling into a manifest exaggeration which would complicate the problem unnecessarily.

First hypothesis.—Figure 7. The first plausible hypothesis that may be made, is that, if the total time of the augmented flow (by which I mean a discharge constantly exceeding 1,200 cubic

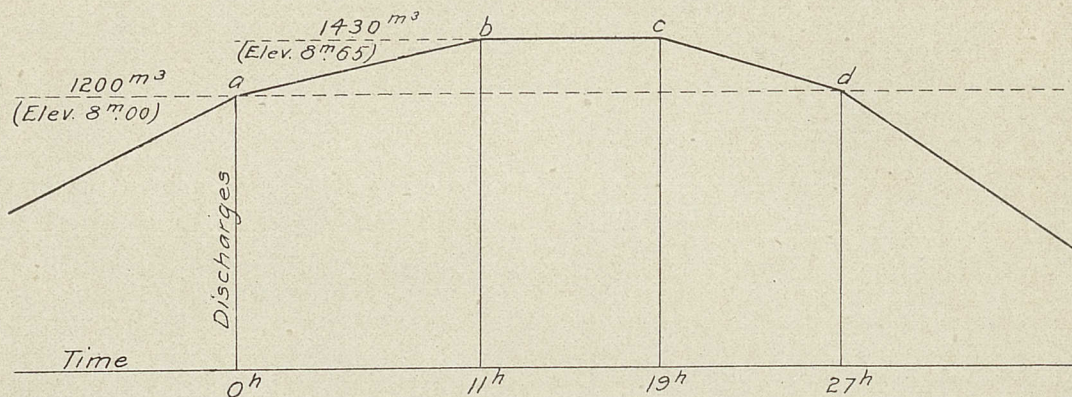


FIG. 6.

meters), is assumed to remain unchanged, the line *b c* representing the period of maximum flow rises parallel to itself from 1,430 cubic meters to 3,170 cubic meters. The line representing the change in augmented flow is shown on figure 7.

The total discharge of the segment representing the part of the maximum flow to be stored is readily computed. Thus:

	Cubic meters.
First phase (increasing).....	39, 006, 000
Second phase (constant).....	56, 736, 000
Third phase (decreasing).....	28, 368, 000
Total	124, 110, 000

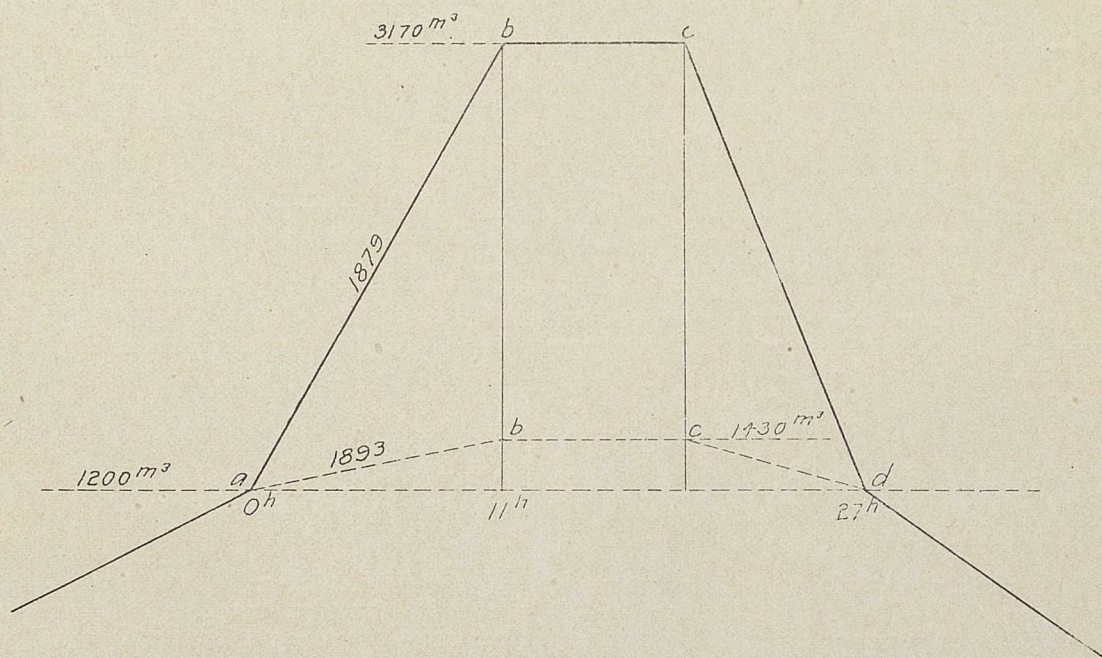


FIG. 7.

The total volume discharged during this time would be 240,750,000 cubic meters.

It does not seem logical to suppose the duration of maximum discharge (3,170 cubic meters) to become longer than that of the 1,430 cubic meters in the flood of 1893; this would be contrary to the customary phenomenon in torrential rivers fed by a comparatively contracted basin, as in the case of the Chagres itself; the duration of maximum flow decreases generally rather

than increases when the volume increases. This fact is explained readily: In a large flood let us consider the period of its maximum flow when at a stand. The intensity of its unit of discharge is then proportionate to that of the hourly rainfall causing it, and its duration is proportionate to the duration of this hourly rainfall. Should the intensity of the hourly rainfall double, it is not probable, but rather contrary to events generally observed, that the duration of this exceptional downpour should increase at the same time; in fact, it is rather the reverse which is noted. The unit of discharge of the flood, during the time corresponding to the contribution of this downpour, supposed to be doubled in intensity, may double, but its duration will probably decrease rather than increase. In making the hypothesis that its duration would increase in proportion to its intensity of discharge, a very improbable supposition is ventured. Nevertheless, I will examine later the consequences of such a hypothesis. On the contrary, it is logical to suppose that the duration of the increasing phase and that of the decreasing phase increase in proportion as the absolute maximum discharge increases. The law of this progression can be inferred in several ways.

Second hypothesis.—Figure 8. For example, let us suppose that the duration of these phases in the two floods to be compared are proportional to the maximum discharge they may attain under this hypothesis, the transformed line would be as shown in figure 8 (the coefficient of increase to be applied being $\frac{3,170}{1,430} = 2.20$).

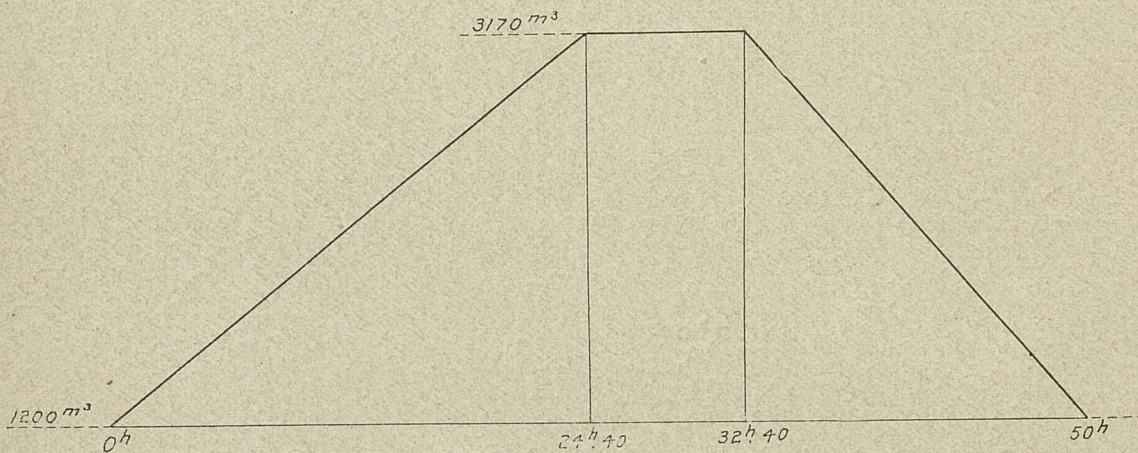


FIG. 8.

The total discharge of the segment of the trapezoid representing the volume to be stored would be:

	Cubic meters.
First phase.....	86,522,000
Second phase.....	56,736,000
Third phase.....	62,410,000
Total	205,668,000

Total volume discharged during the period, 422,000,000 cubic meters.

Third hypothesis.—Figure 9. Another logical hypothesis would be that the duration of the two phases, increasing and decreasing, for the two floods, are proportional to the maximum elevations which the floods may reach, 8.65 meters for the one and 12 meters for the other. The coefficient of increase for this duration in the flood of 1879 compared to that of 1893 would be $\frac{12}{8.65} = 1.38$. The transformed line would then be that shown in figure 9.

The total discharge to be stored would be—

	Cubic meters.
First phase.....	53,828,000
Second phase.....	56,736,000
Third phase.....	39,148,000
Total	149,712,000

Total volume discharged during the period, 298,000,000 cubic meters.

Fourth hypothesis.—Finally, in the transformation method applied above, suppose, however unlikely may be this hypothesis, that the phase when at a stand itself increase in the same

proportion as the two others; in such case its duration would be either 15^h 40 or 9^h 70, according to the method of progression adopted, and the discharges to be stored would become:

By the first method (coefficient 2.20)—

Total duration of the period (59 ^h 60):	Cubic meters.
First phase.....	86, 522, 000
Second phase.....	124, 819, 000
Third phase.....	62, 410, 000
Total	273, 751, 000

By the second method (coefficient 1.38):

Total duration of the period (37 ^h 30):	Cubic meters.
First phase.....	53, 828, 000
Second phase.....	78, 296, 000
Third phase.....	39, 148, 000
Total	171, 272, 000

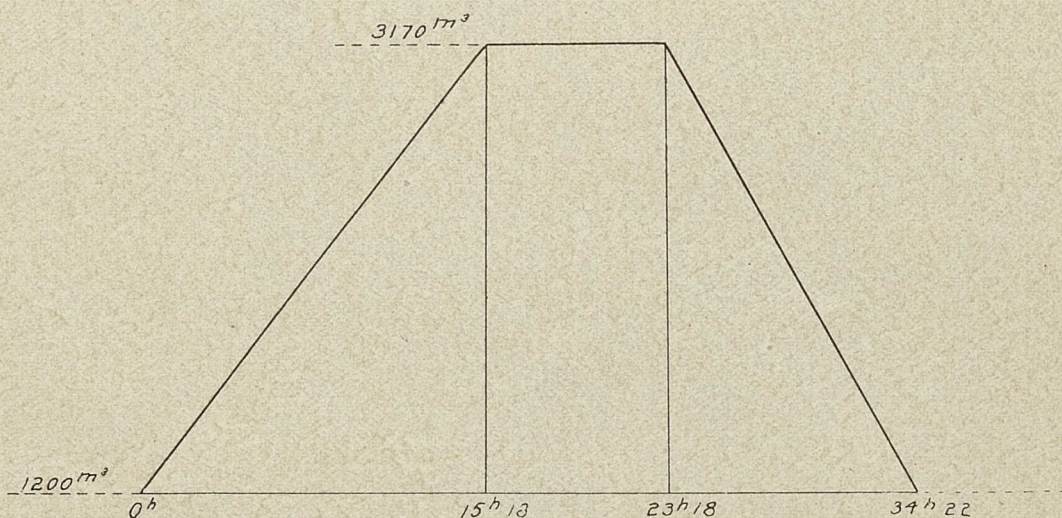


FIG. 9.

Fifth hypothesis.—Figure 10. By the method just used, the two hypotheses, each leading to the maximum result, are those where each of the three phases is increased in duration proportionally either to the increase of maximum discharge or to the increase of the maximum

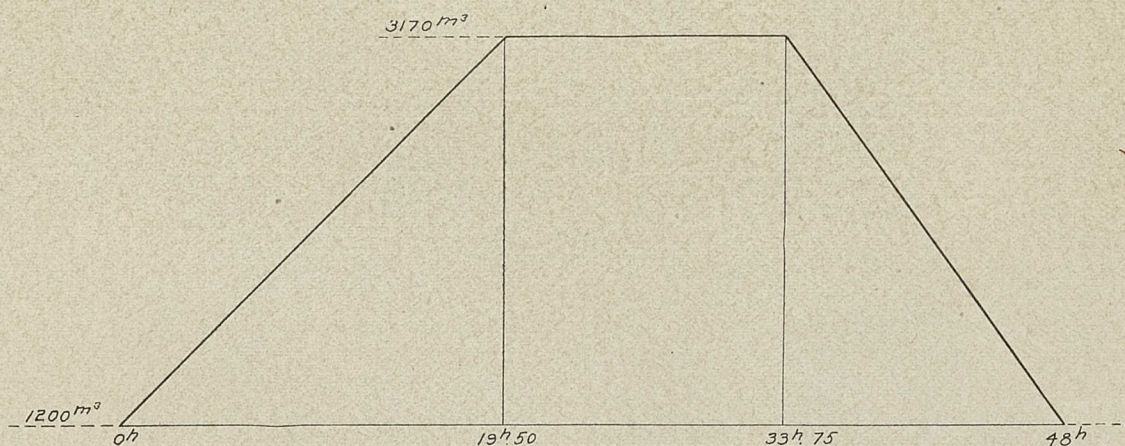


FIG. 10.

elevation. In the first case the coefficient of increase is 2.20, in the other 1.38. Common sense and experience indicate that it is more rational to suppose that the duration of the maximum flow increases proportionally to the maximum elevation rather than to the maximum discharge which may be attained. Therefore it would be nearer to reality, still keeping above it, to take as a coefficient of increase the mean between the two above—that is to say, the coefficient 1.79; then the total period would become $27^h \times 1.79 = 48^h 30$, say 48 hours, distributed in three phases, giving the transformed line shown in figure 10.

The total discharge to be stored would be:

	Cubic meters.
First phase.....	69, 147, 000
Second phase.....	101, 061, 000
Third phase.....	50, 530, 000
Total	220, 738, 000

Total volume discharged during the period, 448,000,000 cubic meters.

In the foregoing analysis I have endeavored to establish upon a plausible and rational basis the proportion of increase in the period while the flood is discharging more than 1,200 cubic meters, and its maximum volume rises from 1,430 cubic meters, reached in 1893, to 3,170 cubic meters, reached in 1879; the most logical conclusion to be drawn seems to be that the period increases in the ratio of 1.79 to 1, and that the duration augments from twenty-seven hours to forty-eight hours. It was necessary also to define the line figuring the flood, beginning at the discharge of 1,200 cubic meters. I have deduced it from that of 1893, by supposing that the shape remains similar and that both maximum ordinates rise from 1,430 to 3,170.

A more general hypothesis may be made, which appears perhaps more rational, and which dispenses with searching for the problematic form of an unknown curve. Thus it may be supposed that, during those forty-eight hours, which correspond in the flood of 1879 to the twenty-seven hours of the flood of 1893, the average volume of the flow, in comparison to the average discharge in the corresponding flood of 1893, holds at corresponding epochs the same proportion, as the maximum discharges reached by the two floods. It would follow that the average discharge for 1879 is obtained by multiplying by 2.20, the average discharge in 1893 for the forty-eight hours of its maximum flow. This average discharge is about 1,260 cubic meters per second; consequently the average discharge for the forty-eight-hour period while the discharge of the flood of 1879 was greater than 1,200 cubic meters, would be 1,260 times 2.20 = 2,640.

The total volume discharged during the period would be: $2,640 \times 48 \times 3,600 = 456,192,000$, say, 457 millions, and the total volume discharged in addition to the constant discharge of 1,200 cubic meters—that is, the total volume to be stored—would be $1,440 \times 48 \times 3,600 = 248,832,000$, or, say, 250 millions.

Among the rational and plausible hypotheses to be applied to the phenomena of the flood of 1893 and the phenomena of the flood of 1879, this latter is the one which is based on the broadest hypotheses and which leads to the largest estimates without exceeding reasonable bounds; it has been adopted definitely for the practical study of the problem of regulating and of storing the large floods of the Chagres.

NOTE IV.—*General programme for the construction of the Bohio works—Probable duration of their construction.*

The most important group of works on the canal or its annexes consists of those to be constructed in the Bohio region, in order to realize the lock-canal project adopted by the company. These works are identical, except for a few details, whatever be the elevation finally assigned to the summit level. From every standpoint they constitute the main factor of the lock-canal problem. The object of this group of works is to transform the most important level of the canal into a central lake by damming the Chagres Valley at this point. This lake will be the summit level itself if it is possible to realize the project where the bottom is lowered to 9.75 meters. Furthermore, the formation of the immense lake by the proposed dam will furnish a radical means for regulating the floods of the Chagres and for so controlling it as to make it an inoffensive neighbor of the canal and an indispensable auxiliary in its operation. Finally, on account of the special problems of construction involved in successfully executing this group of works, the latter will regulate the entire time required for the completion of the canal. For these various reasons the complex group of the Bohio works forms the dominant factor of the canal; therefore it will be very interesting to study, as thoroughly as possible, the programme of construction to be followed and the probable time required to complete the work. This I propose to do now. First, I shall enumerate the works projected at this point.

BRIEF STATEMENT OF WORKS PROJECTED.

As is known the valley of the Chagres at this point presents a very pronounced contraction, reducing its width at the low-water stage to about 100 meters and its width at 20 meters above this level to about 380 meters. Generally this condition is very favorable to the construction of a dam. On the left bank of the Chagres is a bluff called Bohio Butte, consisting partly of rock and partly of a volcanic conglomerate as hard as rock, composed of gravel and boulders of various sizes cemented by eruptive material. On the right bank, facing the bluff, is the slope

of a rocky hill forming a height known as Cemetery Butte. Against these two opposing heights will be abutted the proposed dam across the Chagres Valley. The slopes of these heights present quite a marked steep incline; they plunge rapidly under the thalweg of the valley, which for a considerable depth consists of a thick deposit of ancient diluvium, very compact clay or sandy clay, as shown by the geological section (atlas plate No. 6) drawn from numerous borings. This composition of the soil in the lower part of the valley would not admit of the construction of a secure masonry dam of sufficient height, owing to settling always to be feared, but it admits readily of the construction of an earth dam. This latter type has been adopted for the dam projected at this point. By reason of its functions and of its importance, it is the principal work of the group in question. The general conditions for constructing this dam are stated in the report of the technical committee, and they are shown on atlas plate No. 6. The greatest depth of water will be 20 meters above the bed, and the crest of the dam is set at 3 meters higher. Its total elevation above the lowest level of the foundation is 28 meters. Its length is 280 meters at low-water level and 392 meters at top.

Bohio Butte, on the left bank of the Chagres, is crossed in its entire length by the canal line, and in this bluff will be constructed the flight of two locks, which will conduct to the second canal level. This so-called Bohio level, by reason of the dam transversal to the valley, will form an immense lake extending about 21 kilometers along the direction of the canal and covering an area of about 6,000 hectares at its maximum level. This flight of two locks is the second in importance of the works of the group, and together with the dam will close the valley entirely. The cut to be opened in the bluff to receive these locks has been dug already to a considerable extent by the old company with a view to a sea level canal; its actual mean depth on the axis reaches about the elevation of 13 meters. The original elevation of the highest point of the bluff was 53 meters. The excavations must be carried to -3.50 meters for the upper lock and to -12 meters for the lower lock of the flight. The Bohio Lake, in time of large floods of the Chagres, is likely to receive an important volume of water, as the foregoing discussion has shown; it must hold back a large portion of it at the time of the rise, and this volume will raise its water level from the original elevation of 17 meters to a level depending upon the importance of the flood, which may reach the maximum elevation of 20 meters. At the same time there must pass continuously a volume which may attain a discharge of 1,200 cubic meters or 1,900 cubic meters per second, according to the type of waste weir finally decided upon. This discharge will be effected through two outlets, one on the left of the canal capable of discharging a maximum of 500 cubic meters per second, the other on the right of the canal capable of discharging 700 cubic meters or 1,400 cubic meters a second, according to the system of waste weir adopted. The works constituting these outlets make up the third group of works at Bohio. I shall assume here that waste weirs provided with sluices for a total discharge of 1,200 cubic meters per second, to be distributed between the two, will be finally adopted. The question of the system of the waste weirs is not material from the standpoint of the present note.

The site for the left waste weir is a hollow in Cemetery Butte against which the dam abuts on the right bank of the Chagres. Its fixed masonry sill is at 14 meters elevation; the sluice gates which close it are 3 meters high, and their tops therefore are at 17 meters elevation (normal level of the lake) when they are lowered. The foundation excavation for the masonry sill must go down to 10 meters elevation at the lowest point in order to reach solid ground everywhere; the length of the sill, and consequently of the foundation excavations, is about 700 meters.

The site for the right waste weir is in a depression lying near the top of the divide separating the little valley of the Rio Gigante from another small basin containing the Peña Blanca Swamp. This depression forms a long hollow whose level is at 20.75 meters elevation. The proposed waste weir at this site will have, like the other, a fixed masonry sill at 14 meters elevation, with sluice gates 3 meters high. The length of the masonry sill is 96 meters; the foundation excavations must go down to 9 meters elevation in order to reach solid ground. Since for quite a long distance in the vicinity of the divide the natural land within the future lake is at a higher level than the elevation of the fixed sill of the waste weir (14 meters elevation), it will be necessary to make a cut down to that elevation in order to open to the waste weir a channel capable of carrying the discharge which is to flow through it.

Such is the Bohio group of works. I will now indicate what seems to me to be the rational method which should be adopted in their construction.

GENERAL STATEMENT OF THE METHOD OF CONSTRUCTION.

It is evident that the topography of the bluff bordering the left bank of the Chagres, and across which the canal passes, admits of the construction of the flight of locks in connection with that of the dam, thanks to the nature of this bluff. This determines conditions very favorable to the execution of the general plan for constructing the works and justifies the choice of this locality to the exclusion of any other for closing the lower valley of the river. It is evident also

that the simultaneous construction of the dam and of the locks must not be contemplated; that work will be simplified by dividing it, taking advantage of the natural facilities offered by the location to divert the Chagres through the cut which must be opened through the ridge in any event, so as to be able to build the dam without interference from the river. Therefore, the construction of the dam and of the locks must advance successively, since the site of the locks must for a time be the bed for the discharge of the Chagres while the dam is building. Two general methods of construction are possible; one, in which the somewhat advanced stage of construction of the locks would precede that of the dam, the other in which the construction of the dam would precede that of the locks (except their excavations, which must be made first in any case). The latter method seems to me preferable for several reasons, particularly for two general reasons which alone seem to me decisive. In the first place, it is very desirable to build the dam at the earliest moment, in order to enable it to stand the action of time as long as possible before operating the canal. Secondly, it will not be necessary to wait for the completion of the dam before proceeding with the construction of the locks; it will be sufficient if it has reached a height enabling the Chagres to discharge its waters through the cuts at the waste weirs, which will have been opened previously to their full depth. From that moment the site of the locks will become free again, and it will be possible to construct these works and to complete the dam simultaneously, thereby saving time appreciably as compared with the other method.

METHOD OF APPLICATION.

First phase.—Such is the general method which I prefer. The following is its proposed application: The first operation is the cut at Bohio Butte which is to serve as the excavation for the locks at this site and as a temporary diversion of the Chagres. This cut must be 73 meters wide for locks with two chambers each 25 meters wide. The bottom must be lowered to elevation -12 meters for the lower lock and to elevation -3.50 meters for the upper lock. The excavations need not be lowered to these elevations at the outset; it will suffice to lower them temporarily to the mean elevation $+1$ meter, and to give them a certain longitudinal slope. This is the level which seems convenient and sufficient for the bottom of the temporary diversion of the Chagres during the construction of the dam. At the same time should be built the masonry work at the upper end of the upper lock for a sufficient distance to enable later the floating guard gates to take their place under the pressure of the lake, thus barring the waters of the Chagres from the excavations and acting as a cofferdam to permit the resumption of work on the locks when the time shall have come. The approach basin of the canal above the locks in the Bohio level should have its normal bottom at 7 meters elevation, the same as in the entire level. In order to allow the temporary diversion of the Chagres by means of the lock cut, it will be necessary to dig this basin at once, at the same time as the cutting of the butte, and to lower its bottom to that of the cut, that is elevation 1 meter, between the site of the locks and the point where the canal line encounters the bed of the Chagres, opposite Buena Vista; that is, for a distance of about 400 meters. This done, by building on the site indicated on the general map (plate No. 4) a temporary dam, the crest of which should be at elevation 7 meters, the Chagres will be diverted into the open cut through the butte, thus leaving free the site of the definitive dam. This combination of works represents what I shall term "The first phase of the programme of construction." Its completion will require not less than two years, including the time for preparation and for organization. The estimate of the excavations in the cut at the butte within the provisional limits stated above, is about 700,000 cubic meters. During this phase the foundation of the definitive dam will have been prepared on the sides of the Chagres Valley and the first steps necessary to construct this work taken, so that its construction proper, on a large scale, may follow immediately the completion of the works of the first phase. In my opinion nothing will prevent starting at about the same period, the enrockment of large blocks below the dam, at least up to the low-water level of the Chagres, and also the cofferdam to be filled with concrete to form a protecting wall above the dam. These last works may be constructed in great part without requiring the diversion of the river; they may then be considered to be in a very advanced stage at the end of the first phase above defined, and that at that moment it will soon be possible to attack the heavy work of the dam itself. Then begins the so-called "second phase of the programme," when the Chagres, diverted by means of the temporary dam at Buena Vista, will discharge its waters through the opening of the locks. With this opening, and the height of 7 meters above the bottom of the bed, adopted for the diversion dam, this diversion will suffice for the discharge of the river up to the volume of about 650 cubic meters per second without overflowing the provisional dam. Therefore, only during serious floods and consequently only for short periods during the year will the diversion dam be exposed to be overflowed and the yards of the definitive dam be invaded. The arrangements for constructing this work have been studied in view of these conditions, and, while under construction, it might be submerged by a flood without danger. We will soon see that this event can not happen when the height of the dam rises above 13 meters. Even consid-

ering such an extreme accident, which is the most unfavorable case from the standpoint of a submergence of the dam by a large flood, it will be recognized that even then the overflow from above would be rather weak. Indeed, the level of the water in the immediate vicinity below the dam would rise naturally about 10 meters or so, as happens without a dam; the discharge over and above the dam would take place with a fall of only a few meters. It is mainly in order to protect the work while under construction against the effects of a submergence that has been provided the important mass of large rocks placed along its downstream slope, which mass will be deposited gradually, so as to be always in advance of the mass of earth.

Second phase.—Simultaneously with the main body of the dam, even without waiting so long, work will be started on excavations for the waste weirs which will become later the outlets of the lake—one in the hollow of Cemetery Butte, the other at the Gigante divide. These excavations will form two openings having a total width of 166 meters, to be lowered, the left one 70 meters in width to elevation 10 meters, the right one 96 meters in width to elevation 9 meters. Thus prepared for building the masonry work of the fixed sills of the waste weirs, these cuts will be left open until the dam is completed, and even during the greater part of the masonry work of the locks. They will serve as effective outlets, through which, concurrently with the opening of the locks, the Chagres can discharge its waters as soon as its level, raised by the gradual construction of the dam, has reached the bottom of the said excavations. By the ordinary formulæ of hydraulics applied to the conditions just stated, it will be found that, taking elevation 13 meters as the lake level above the dam under construction, the discharge which would pass through the wide openings of the waste weirs and through the opening of the locks, might attain about 3,000 cubic meters per second; that is to say, the maximum discharge to be anticipated. It follows that the dam would no longer be liable to act as a waste weir, and that above that elevation it would be protected against any submergence. Under these conditions there would be no need of continuing the enrockment on the downstream side above elevation 13 meters, or, for greater security, above elevation 14 meters.

Assuming elevation 14.5 meters as the lake level at the dam, the discharge through the openings at the waste weirs alone, without the cooperation of the opening of the locks, would reach 3,000 cubic meters per second, which is the maximum to be anticipated. At that moment it would be possible to exclude the waters from the cut for the locks by installing the floating guard gates, preparation for which had been made during the first phase, and to resume and complete the construction of the locks. This will be the end of the second phase of the programme and the beginning of the third phase. I believe an estimate of not less than four years is necessary for the completion of the second phase, taking into consideration the natural delays inherent to works on the Isthmus, and unexpected incidents which may cause some loss of time. The first two phases might then be completed in six years.

Third phase.—The third phase includes the completion of excavations for the locks which have been lowered temporarily only to the average elevation of 1 meter; the final construction of the masonry work of the locks and of all mechanical works, such as apparatus for filling and emptying the chambers, the installation of gates (prepared essentially in advance) and other machinery, etc.; the completion of the dam; finally, the construction of the masonry work of the waste weirs and of their metallic parts. These last works will be executed readily during periods of low or of medium stages of the Chagres, which will be discharged again through the locks as soon as work is sufficiently advanced. All the works just enumerated constituting the third phase of the programme will occupy a total period which it seems to me should not be estimated at less than four years. The completion of the programme would therefore require ten years. This period, ten years, I consider as the regulating term for delays of execution for all the works of the canal and its annexes, since, whatever be the project adopted, the Bohio group remains the same and will require the same time in all cases.

MATERIALS AND MEANS OF TRANSPORTATION.

The materials required in the construction of all these works are found in their vicinity, and the organization of the means of transportation will be effected readily. The so-called Bohio quarry, now for a long time operated by the railroad company, will supply the materials for all the masonry work and for the enrockment of the dam. This quarry, of which the capacity for production is considerable, is situated to the left of the line of the railroad at about 500 meters from the dam. The earth required in the construction of the dam itself will be found on the banks of the Chagres in the vicinity. These banks consist of a thick layer of argillaceous sandy deposits, which are very suitable for the works in question; their working and their transportation to the points where needed will be effected readily by the ordinary means of small railroad tracks. It goes without saying that the operations will require the fullest use of mechanical means. The works only at the waste weir of the Gigante, situated at about 5 kilometers from the locks, which will also require the use of materials from the Bohio quarry, will call for the

laying of special tracks over quite uneven land. These tracks may be narrow, if it be considered too expensive to lay wide tracks for heavy rolling stock. Important earthworks will have to be executed at this point, and heavy rolling stock for that use would be more advantageous if the preliminary works for its use should not entail too much expense.

PARTIAL DEVIATION OF THE PANAMA RAILROAD.

The programme of construction of the Bohio group involves necessarily the construction at the outset of a work not connected directly therewith, and belonging to another class of works, yet indispensable at least partially at once. I am referring to the Panama Railroad deviation. Indeed the railroad from Colon to Panama cuts the canal line twice, first near P. K. 36 crossing from the left to the right of the canal, then again near P. K. 56 crossing from the right to the left. As these crossings are not admissible on so important a navigable way, the railroad must be deviated, so as to remain entirely on the left bank of the canal where lie both its terminals. Moreover, for quite a long distance, beginning at Bohio, this railroad is at a lower level than the probable level of the future lake; consequently it is necessary to extend the deviation over the entire distance which is liable to be submerged. These various reasons lead finally to a deviation of the actual line on the entire distance lying between a point about 500 meters above the Bohio station and Miraflores; that is, for about 42 kilometers.

The actual station at Bohio, in the vicinity of the site of the dam, is at elevation 12.20 meters. From that point the railroad remains in the Chagres Valley, as far as the neighborhood of San Pablo, at a level low enough to be exposed to be submerged by ordinary floods, so soon as the temporary dam for diverting the Chagres through the opening of the locks during the construction of the final dam is built. It is therefore essential that at that moment the part of the railroad deviation lying between its origin near Bohio and the vicinity of San Pablo shall have been built, possibly connecting temporarily this part of the new line with the existing line, which is not distant at a point a little above the Barbacoas bridge, by which the Panama Railroad crosses the Chagres. The rails on that bridge being at elevation 18.90 meters; that point is indicated as the temporary link.

The construction of the works of this partial deviation relates therefore to the first phase of the programme of construction of the Bohio group, and must be carried out simultaneously. This seems to me possible; the length of the part of the new line to be built will be about 13 to 14 kilometers. From San Pablo on, the actual line escapes the field of submergence of the future lake, which can be kept down a few meters until the final construction of the waste weirs. This partial line can therefore be used until the end of the canal works, and there will be ample time for completing the final railroad deviation between San Pablo and Miraflores.

MISCELLANEOUS REMARKS.

In the foregoing analysis of the successive phases of the programme of construction of the works of the Bohio group, I have assumed that the waste weir at the Gigante divide would be built with regulating sluices. It is apparent that neither the program nor the successive works involved in carrying it out will be modified if a waste weir without sluices be adopted. Only the arrangements of this waste weir would be altered, as well as the earthworks relative to it, and this is a detail of construction not material to the general program.

I will close this note with a remark applicable to the two systems to be considered in reference to the Gigante waste weir. I have remarked before that, on account of the elevation of the land within the lake in the vicinity of this waste weir, it will be necessary to dig within the lake a channel for quite a long distance, in order to carry the volume to be discharged. As we have seen, the final construction of the dam would require the opening of the waste weir down to elevation 9 meters, which is the elevation of its masonry foundation on rock. Temporarily this cut must remain open to that depth, in order to allow the discharge of the floods of the Chagres while the dam is building. It is evident that this will require the digging of the channel leading to the waste weir, so as to enable it to feed the outlet temporarily lowered to elevation 9 meters. This channel must be provided therefore with a sloping bottom ending temporarily at that elevation, which will require important excavations in addition to the amount strictly demanded for the final construction of the waste weir.

NOTE V.—PROGRAM OF OPERATIONS AT THE CENTRAL CUT.

Various sections of the cut and estimates of excavations.

The central cut through the range constituting the divide between the slopes of the two oceans begins at P. K. 46.400 beyond the Obispo locks and ends at P. K. 56.600 above the Paraiso lock. It forms the entire summit level in the 20.75-meter project and only part of the summit

level in the 9.75-meter project. This cut consists of two sections characterized by very different topographic conditions. The first section extends as far as P. K. 53,600, and consists of the so-called Emperador range; its elevations are comparatively low and its excavations moderately deep. The total excavations required for a total distance of 7 kilometers is 12,400,000 cubic meters in the 20.75-meter project and 18,700,000 cubic meters in the 9.75-meter project. The second section extends from P. K. 53,600 to P. K. 56,600, and consists of the Culebra divide; it will require far deeper excavations. The total excavations required for a total distance of 3 kilometers are 10,400,000 cubic meters for the 20.75-meter project, and 12,700,000 cubic meters for the 9.75-meter project. These estimates would become 11,700,000 cubic meters and 14,500,000 cubic meters, respectively, in the 20.75-meter and 9-meter projects with enlarged profiles. In this section special mention should be made because of the depth of the excavation of the portion lying between P. K. 53,600 and 55,500, consisting of the so-called Culebra divide, and which alone for a distance of 1,900 meters requires 8,900,000 cubic meters to be excavated in the 20.75-meter project and 10,900,000 cubic meters in the 9.75-meter project. These estimates would become 10,000,000 cubic meters and 12,300,000 cubic meters, respectively, in the 20.75-meter and 9-meter projects with enlarged profiles.

As I stated in Note I, all these estimates are made without taking into consideration the excavation already made by the New Company in constructing the so-called preparatory cunette, this excavation being considered an elastic margin to meet contingent expenses in the remaining excavations.

This outline of general conditions in the work projected in the central cut shows at once that in any case from the standpoint of duration of construction, and therefore from the standpoint of the organization required for the work, the gist of the problem centers in the portion of the range lying between P. K. 53,600 and 55,500, which alone in either project constitutes two-fifths of the excavation of the entire cut. A priori it is evident that if the work be prosecuted with equal activity, far less time will be required to complete all the other parts, or, what comes to the same thing, for the same duration far less activity elsewhere will be required. This remark leads to the following conclusion, which is undeniable, logically and economically. It is of real importance to distribute the total work as uniformly as possible according to the longest term required for each class of works, with a view to reaching as closely as possible the average of the total number of laborers to be employed. But it is in the first phases of construction that the excavation of the Culebra range proper can be prosecuted most actively, and will call for the largest number of laborers. Necessarily the active prosecution, as well as the number of laborers to be employed, must decrease when great depths have been reached. Therefore, in order to maintain a certain uniformity in general activity and in the number of laborers distributed over the total works of the central cut, it will be rational to force work on the Emperador range and the lower portions of the Culebra excavation between P. K. 55,500 and 56,600 only after very considerable work has been done on the deep cut of the Culebra; that is, only after an interval of several years. I think a start of at least three or four years may well be taken on the latter before attacking the other parts of the central cut. This method, which is very judicious when we consider the advantageous distribution of labor as a problem by itself, will have a decided advantage from another standpoint, as has been shown in Note I. It will avoid resuming work on excavations already made if, after three or four years of active experience in the deeper part of the Culebra Cut, the 9.75 meter instead of the 20.75-meter project is adopted. As regards this local section of the central cut, it is known that the upper parts of the profiles coincide in the two projects, and that work done in the first three or four years is therefore applicable to both, whereas this is not the case as to the remainder of the cut. Therefore it will be advantageous if nothing or hardly anything has been done there when a final decision is reached.

GENERAL DIVISIONS OF THE PROGRAM OF THE WORKS.

In my opinion, this is the first principle to regulate the organization of works in the central cut, namely: Immediate forcing with the greatest activity the work on the portion lying between P. K. 53,600 and 55,500; some three or four years later, go on with the rest. I propose now to consider not the actual details of construction, which would be beyond my purpose, but the general conditions of organization for a practical plan of construction which can be applied advantageously to these works in a manner to throw light upon their total duration and the average number of laborers necessary. This does not require the consideration of those parts of the cut on which work may be delayed for several years; evidently the period of construction will depend especially on the part lying between P. K. 53,600 and 55,500, consisting of the deep Culebra Cut. As to the number of laborers necessary, it can only be approximated by adopting as close an estimate as possible as to the production of each laborer; after that the knowledge we possess of the volumes to be excavated will suffice.

Therefore I have considered only the organization which should be adopted in constructing the part of the cut lying between the points stated above. I hasten to say that this study does not pretend to afford the only solution of the problem; it only indicates a solution which seems logical and practical and which forms a plausible basis for appreciating the questions raised.

METHOD OF CONSTRUCTION APPLICABLE TO THE DEEP CUT OF THE CULEBRA.

GENERAL ORGANIZATION.

The Culebra Cut proper, as defined above, is 1,900 meters long, of which only the portion lying between P. K. 54,100 and 55,300, approximately, can be the object of a general organization, as it forms a homogeneous whole from the standpoint of operation, ways and means of transportation, and sites to be used for dumping. This portion, about 1,200 meters long, can constitute a collection of yards operated according to the same method, progressing simultaneously, necessarily using the same dumps and which ought to be under one local management. The other two portions extending the cut at its two ends must necessarily be subject to different methods of operation; they will have their own dumps and special means to gain access thereto. They should be worked simultaneously with the portion just referred to, but without direct and intimate connection with it in reference to the organization and to the means to be used.

For an estimate of the time required to construct the entire Culebra Cut, it will suffice to find the time necessary to construct the portion lying between P. K. 54,100 and 55,300.

The method of construction studied is based on the use of excavators and of large dirt cars for transportation. The general plan consists in operating simultaneously as many fronts of attack, similar in composition and in work, as can be installed, taking into account the facilities for dumping, which will vary with the widths of the cut at the different levels.

The plans and profiles annexed to the present note (plates Nos. 15 and 16) show the general organization of the fronts of attack and the successive phases of the progress of the work. The dumps where excavations are delivered are the Lirio dumps toward Colon, and those in the valley of Mallejon toward Panama. Two fundamental principles govern the organic study, which may thus be explained: The first consists in independence as to outlet for each front of attack, permitting loaded trains to leave and empty trains to take their places. On each front the train loading has a track connected directly and immediately with a general line of tracks ending at the dumps, without borrowing other working tracks at any point. The second principle consists in establishing, before arriving at the dumps themselves, a permanent transfer station where will meet, on the one hand, all loaded trains approaching the dumps whose previous routes change necessarily, and, on the other hand, all empty trains returning from the dumps. This station once established will work without any change from beginning to end; it constitutes an exchange station where the train engines may shift from front to rear, or rather where full trains and empty trains may exchange engines, so that the trains can always leave the loading point engine in front and return with engine in rear, and, on the other hand, travel on the route thence to the dump with the engine in rear and come back with engine in front.

The plate shows by means of elevations that the exchange station on the Lirio dump route must be placed at 70 meter elevation, and that this station can only be approached by trains coming from the cut unless excessive grades be admitted, when the tracks at the loading point do not attain an elevation less than 59 meters. Admitting an excavation 4 meters lower, we see that elevation 55 meters is the extreme limit which can be subserved by the Lirio dumps. Thence forward the excavations must be dumped at the Mallejon. The exchange station on the route to the Mallejon dumps must be placed at elevation 46.50 meters in order to be able to cross on a higher grade the Panama railroad, whose rails near this point are at elevation 42 meters. The plate shows the possibility of reaching from the cut the station placed at elevation 46.50 meters without excessive grades so long as the track platform at the starting place is not lower than elevation 29 meters, or the excavation bottom is not lower than elevation 25 meters. This is the extreme limit which can be attained without resorting to special means, such as raising the material before loading it on the cars, or raising the cars after having received these loads before starting toward the exchange station.

Naturally, it is possible to think of other methods of execution and of other general systems of organization by which similar results may be reached, but as regards production, I do believe that practical results can be reached materially different from those obtained by applying the method briefly outlined above and the successive phases of which are now to be considered.

The portion of the cut referred to is divided into four sections, each about 300 meters long, operated under identical conditions and progressing simultaneously, so as to maintain among them the same conditions relative to level. It will suffice therefore to consider the progressive advancement of work in one of these sections.

The total program is divided into 16 phases, each corresponding to the construction of benches 4 meters high and varying in width, by means of a certain number of excavators, which number will vary from one phase to the other. The phase is defined by the condition that the excavators do not have to move vertically during its entire duration. The transition from one phase to the other takes place when it is possible to begin work on the bench below.

SUCCESSIVE CONDITIONS OF THE WORK AND DURATIONS OF THE VARIOUS PHASES.

First phase.—The first phase corresponds to the general organization of fronts of attack and to the removal of the irregular mass of material lying above the elevation 87 meters. This mass will probably have to be removed by means of hand labor, and the phase will absorb about one year. At the end the condition will be found as illustrated on diagram 2 on pl. 16; work can be started at the same time on three levels, lowering the benches to elevations 83, 79, and 75 meters.

Second phase.—The installation effected at the beginning of this phase is illustrated, as above, by pl. 16. The bulk to be removed is shown by the yellow shade. Three excavators work forward, and widen their platform at the same time, and when the three benches shown by the yellow shade are cut away there remains a platform at elevation 75 meters where can be put another installation cutting to elevation 71 meters; here begins the third phase.

The cubic quantity to be removed in the second phase for one section is 63,000 cubic meters, according to the regular profile, after deducting the cunette already excavated. However, taking into account the additional cubic quantity to be removed resulting from unexpected events, such as caving in and widening on account of the radius of the curves, etc., it is proper to increase by 15 per cent the estimates based strictly on the theoretical profiles. I estimate, therefore, the quantity to be removed in this phase at 72,000 cubic meters.

The capacity of one excavator (excavation and removal) for a day's work of ten hours can not be placed at more than 400 cubic meters under most favorable conditions. This figure is obtained as follows:

A loaded train will consist of a maximum of 20 cars, which, holding each 3.80 meters measured in place, represents 76 cubic meters. One hour (three minutes per car) is required to fully load the train; twenty minutes for moving the train out of the cut, including preparations and accidental delays, and as much for bringing an empty train into its place; therefore one hour and forty minutes are required for each train loaded and cleared. Thus six trains may be run per day for each excavator working at the maximum, no stops or delays taking place, which gives an output of $76 \times 6 = 456$ cubic meters. However, inevitable stops of excavators, damages to tracks or to cars, delays in the circulation on account of many trains using the same tracks, etc., must be taken into account. Reducing by one-tenth for these causes, the theoretical maximum output will become rather moderate; that is to say, an output of 400 cubic meters for one excavator and one full working day of ten hours.

But full working days of ten hours are possible only during the dry season, and the experience of those who have directed excavations on the Isthmus has shown that a reduction of 25 per cent is to be anticipated during the rainy months as compared with the work of the dry months. The year may be divided on the average into seven strictly rainy months and five dry months. Consequently, the daily output in the whole year will be 400 cubic meters for five months and 300 cubic meters for seven months, or an average of 340 cubic meters. This is the daily practical yield of one excavator to be used in estimating the period of operating each phase.

The second phase, comprising 72,000 cubic meters, will require on this basis, with three excavators, a total duration of seventy effective working days, a month consisting on the average of twenty-three working days (deducting Sundays and holidays). Out of these twenty-three days must be deducted the time absorbed by track injuries and usual incidents, or a minimum of three days per month, reducing to twenty days the real month's work so far as effective work is concerned. The seventy working days stated above are therefore equivalent to three and one-half months. In addition, some time is required at the end of the phase to remove the tracks and the excavators, and effect the installation for the beginning of the third phase, as illustrated by diagram 3 on pl. 16. Allowing ten days for this purpose, and considering the four sections which work at the same time, four months will be required to complete this phase and to start on the next.

Third phase.—The time required for the third phase is figured readily by the same method and on the same fundamental basis. Its cubic estimate, as exemplified by the pink shade in the diagram, is 87,000 cubic meters theoretically, and 100,000 cubic meters to all practical purposes. This excavation will be made simultaneously at four working points. Taking 340 cubic meters per day, or 27,000 cubic meters per month of twenty real working days, the time required will be about four and one-half months, including ten days to start on the fourth phase.

Fourth phase.—This phase is identical to the one preceding, therefore it will require four and one-half months.

Fifth phase.—The fifth phase will require also four and one-half months.

Sixth phase.—The same conditions, requiring four and one-half months.

Seventh phase.—The same conditions, requiring four and one-half months.

Eighth phase.—The installation here is different; a fifth excavator is working and a cunette is dug below elevation 51 meters, while each of the others dispose of a quantity corresponding to the same in previous phases. This cunette has a far smaller volume, but by reason of interference in its construction it will require the same time to widen it as for the higher portions. Finally, the same time as for the last, or four and one-half months, will be required to complete this phase.

Ninth phase.—This phase is divided into two periods. In the first, four excavators working together clear the portions illustrated by the light-gray shade in diagram 9 on pl. 16. When this work is finished, there is at elevation 47 meters a platform wide enough to install another excavator and the tracks in rear, whereby work may be started on a cunette at elevation 43 meters. While this cunette is digging, the other four excavators continue to widen the dark-gray shaded portions; this is the second period. The time required to finish the total phase is that required by the four excavators to clear and widen the portions shaded in light gray and dark gray. The excavation of the lower cunette, being made in connection with the preceding work, does not entail extra time. The total estimate of the portions above stated is 120,000 cubic meters geometrically, which amounts to 140,000 cubic meters practically. On the above established basis of 27,000 cubic meters per month, with four working heads, the time required to complete this phase, including ten days for the installations of the next phase, will be six months.

Tenth phase.—This phase is divided also into two periods. In the first, four excavators clear the portions shaded in light yellow in diagram 10, pl. 16, but the upper excavator having less to do, finishes earlier, and is not used further. It is necessary, therefore, from the standpoint of the time required to consider only the work of the other three excavators. In the second period, these three excavators continue to clear the portions in dark yellow, while another opens a cunette at elevation 39 meters. The total time required to complete this phase is that consumed by the three excavators at elevations 47 and 51 meters in completing their portions. The total estimate for these three portions is 120,000 cubic meters geometrically, which amounts to 140,000 cubic meters practically. The month's estimate with three excavators is 20,000 cubic meters. The total time, including ten days for preparing the next phase, will be seven and one-half months.

Eleventh phase.—This phase is identical with the foregoing as to the time required, which will be also seven and one-half months.

Twelfth phase.—Same conditions as for the preceding. Time, seven and one-half months.

Thirteenth phase.—The total estimate for excavations is illustrated by the portions in light gray and dark gray of the two upper benches, as shown in diagram 13, pl. 16. The volume is 67,000 cubic meters theoretically, which amounts to 77,000 cubic meters practically, with two excavators working together. The month's estimate will be 14,000 cubic meters and the total time, including the ten days, will be six months.

Fourteenth phase.—Same conditions as above. Time, six months.

Fifteenth phase.—The total time here is that required to clear with one excavator the portion between elevations 27 meters and 23 meters, shaded in pink in diagram 15, pl. 16. Meanwhile the upper excavator clears its portion, and preparations are made for the sixteenth phase. The estimate for this portion is 24,000 cubic meters geometrically, counting as 27,000 cubic meters practically. The volume possible with one elevator per month would be 7,000 cubic meters upon the basis previously admitted, but as certain means must be resorted to, in order to remove excavations from benches at low elevations, a reduction should be made, and 6,000 cubic meters, instead of 7,000 cubic meters, is taken as the basis. The total time to complete this phase will then be about five months.

Sixteenth phase.—The sixteenth phase, and the last, consists of: First. The excavation of the remaining portion between elevations 27 meters and 23 meters or a volume of 25,000 cubic meters, requiring about four months, during which the digging of the cunette of the last layer will be completed. Second. The excavation of this last layer beyond the cunette. The estimate for this last portion is 23,000 cubic meters, its thickness being taken as 3 meters; it can be removed with one excavator in four months, at 6,000 cubic meters per month. This phase will require, therefore, eight months.

RECAPITULATION.

In adding up the partial intervals stated above for each phase, the total time required to complete the section referred to is as follows:

	Months.
First phase.....	12
Second phase.....	4
Third phase.....	4.5
Fourth phase.....	4.5
Fifth phase.....	4.5
Sixth phase.....	4.5
Seventh phase.....	4.5
Eighth phase.....	4.5
Ninth phase.....	6
Tenth phase.....	7.5
Eleventh phase.....	7.5
Twelfth phase.....	7.5
Thirteenth phase.....	6
Fourteenth phase.....	6
Fifteenth phase.....	5
Sixteenth phase.....	8
Total (8 years).....	96.5

During the same time it will be easy to excavate the two portions of the cut which inclose the section just considered, and which complete the Culebra Cut proper. In addition to the time stated a year will be taken to complete the walling of the wetted sides of the canal and to give the finishing touches to the work, so that nine years will be required for the excavations in the project with a bottom at elevation 20.75 meters, providing no serious complications arise, which is hardly probable.

This study is based not upon suppositions as to possible yearly output, but upon daily results which can be counted upon from a definite organization acting under real conditions. Its conclusion is that the central cut in the 20.75-meter project seems to require about the same time as the Bohio group of works. This conclusion induced that adopted by the technical commission in its report of November 16, 1898.* It may evidently be hoped, as is much to be desired, that a greater degree of rapidity may be attained; in that case the realization of the 9.75-meter project may be brought about. I have not been able yet to make a similar analysis for the other projects.

Before closing this note I wish to call attention to the fact, well evidenced by the foregoing study, of the enormous difference between the theoretical output of any excavating apparatus (an excavator in this case) and the real practical output, taking into account the inevitable conditions of place and of climate. I have been led to estimate at 340 cubic meters the daily practical yield of an excavator. At first blush this figure may seem very small, considering the high possible efficiency of such apparatus to-day. After analyzing all the conditions, however, it will cause less surprise when it is considered that this mean yield of 340 cubic meters per day during the entire year assumes a capacity of 1,200 cubic meters of loose débris to be loaded by the excavator in ten hours of continuous work, which is very high.

A volume of 1,200 cubic meters of loose débris equals 760 cubic meters in bulk. Therefore it is only this bulk which would be loaded continuously by the excavator working for ten hours. For each loaded train, which requires an hour's work, forty minutes are spent in discharging, that is, forty minutes are lost in one hundred; hence a first reduction of 40 per cent from the excavator's working time, which reduces the estimate from 760 to 456 cubic meters. Then come reductions from the real number of working days in a month, on account of unavoidable accidents in the general operations of complicated yards; finally, reductions owing to complications during the rainy season, which reduce still further this estimate of daily output from 456 to 340 cubic meters in an average including the entire year.

The question of laborers will form the subject of a special note considering this subject for the entire project.

NOTE VI.—*Program for the entire earthworks and for the constructions along the canal.*

General remark.

I do not intend, nor is it my function, to study in detail what local organizations should be adopted in the construction of the various canal works or what methods should be applied. These are special questions, which can be profitably examined only at the time of construction and with the cooperation of specialists. My aim is to state general ideas relative to the distribution naturally to be anticipated, the order in which the several classes of works in the general plan of the canal should be built, and the time and the number of operatives deemed necessary for

executing each of them. In my opinion, the fundamental idea governing these studies, outside of the a priori necessity of completing the undertaking within the time proposed, is the most economical distribution of expenses, including the indirect costs as well as the actual outlay for the works, and, above all, such a distribution of labor as will facilitate its being recruited as readily as possible. A priori, it is evident that the best conditions are those tending to equalize the yearly averages.

GENERAL DISTRIBUTION OF THE EARTHWORKS.

The earthworks of the canal can be grouped into four main categories, characterized by the special conditions which they offer, and by a greater or lesser urgency for undertaking them. These are (1) the earthworks of the large central cut; (2) the earthworks of the two maritime levels; (3) the other earthworks of the canal proper; (4) the earthworks of diversions lateral to the canal between Bohio and the sea. From a mere consideration of the quantities and of the length of each group and of the modes of application of labor, it is evident, a priori, that the intervals of time strictly necessary to complete these various groups are very different, supposing they are worked with the same activity, and this implies that they need not be worked with the same activity in order to complete them in the desired time. Therefore, for the reasons stated above, it is of the utmost interest to adopt for each group a successive order of working, so as to obtain the greatest uniformity in the total annual progress. It goes without saying that the first two years, devoted to organization and to attaining gradually a normal order of progress, will be exceptions and will produce smaller results.

The group of earthworks of the central cut is the most important, and doubtless must be undertaken without delay. Work on it will continue throughout the entire period, excepting the last year, which must be reserved for revetting the banks below water and for the finishing touches. We have seen (Note V) that simultaneous work is not required on the entire length of this central cut; on the contrary, works should have progressed on the main Culebra cut proper for three or four years before starting on the remainder. Among other advantages, this causes conditions as constant as possible as to the employment of labor over the entire works of this cut during the whole time.

The second group of earthworks, that of the two maritime levels, consists in great part of dredgeable materials, and consequently can be executed much faster than earth cutting on dry land. The total volume distributed between the two levels and covering long distances is only 16,000,000 cubic meters. There is no doubt that it will be easy to execute it in five or six years at most, and there is a double advantage in deferring it until near the end. In the first place, there will thus be avoided any exaggerated demands for labor, which will be excessive at first, not only for the main line, but also for important excavations required by the constructive works. Secondly, these maritime levels, especially that on the Atlantic, will remain exposed to deposits from external contributions as long as these have not been excluded; and by undertaking their excavations too soon there would be danger of partial refilling. These various reasons make me think that the dredging of the two maritime levels should not figure as a part of the general programme until the last five or six years, it being understood that work should be carried on so as to be distributed uniformly in respect to time.

The third group consisting of the other levels (excluding the large central cut which alone constitutes the first group) should be undertaken at the outset, to balance the works deferred to the end and thus to maintain the distribution of labor. Moreover, there is a special reason concerning the Bohio level, which calls for the most important excavations in this group, since the lake which will develop gradually as the Bohio dam rises, might otherwise hinder seriously the progress of the excavations. It will be opportune in this connection to widen certain parts of this level outside of the normal section of the canal in order to facilitate the discharge in large floods. All the earthworks of this group can be completed readily during the first four or five years.

The fourth group, comprising lateral diversions to be opened or completed between Bohio and the sea for discharging the waters from the outlets of the Bohio Lake or from secondary tributaries, represents a volume comparatively unimportant, part of which can be dredged. There is no objection to undertaking this work in the last four years.

The general programme just stated for distributing the earthworks of the canal and the successive order in which to undertake them, leads to the employment of a number nearly constant of operatives throughout, excepting in the first two years of preparation, and in the last year, which is reserved in part for special works. Such should be, in my judgment, the primary aim in view of which should be practically decided the question of ways and means.

GENERAL DISTRIBUTION OF WORK OF CONSTRUCTION.

The construction works projected along the canal proper are the locks and the dams connected with them. I have already discussed the Bohio works in detail in Note V. I showed that the groups there would absorb the total period of the construction of the canal or, rather, that it would be the factor regulating that period, and I indicated also the reasons for the distribution and the order of succession of the various works of this group. I shall not refer to them here.

In order to determine the favorable time of constructing the other locks, I consider as a primary basis of this study that the completion of a group of locks will require five years, including excavations, masonry, and mechanical parts. In view of a judicious employment of the special labor required for this class of works and also from an economical standpoint, it would be logical to divide the entire number of locks to be constructed into two series, each comprising equal phases and a nearly equal amount of work. However, inasmuch as the construction of the Obispo and of the Paraiso locks is subordinate to the final decision as to what shall be the elevation of the summit level, it will be impossible to undertake it until the experience gained in the works of the central cut has made such a decision possible. This leads to a somewhat unequal classification of the work of the locks, the second phase calling for six years instead of five and beginning one year before the first ends.

Thus the first series would comprise:

(1) The excavations of the Bohio locks, of the Pedro Miguel locks, and of the Miraflores lock.

(2) The masonry and accessory works in the last two groups.

The second series would comprise:

(1) The excavations of the Obispo and Paraiso locks.

(2) The masonry and accessory works regarding the Bohio locks, the Obispo locks, and the Paraiso lock. In case the 9.75-meter project should be adopted instead of the 20.75-meter project, on which is based my study, all that relates to the Obispo and Paraiso locks would disappear.

As to the dams little need be said, except as regards the Bohio dam, which has been discussed in the foregoing note. The others pertaining to the canal proper, the most important of which would be suppressed in the 9.75-meter project, can be built readily in the last two years, including earthworks and masonry.

RÉCAPITULATION.

The general programme of the chronological order of succession of all the canal works, other than those comprising the Bohio group, which have been specially considered in the preceding note, may be summed up as follows:

GENERAL EARTHWORKS.

First group (central cut).—Work to be distributed over the entire time, starting on the Culebra cut proper at the very outset, and four years later undertaking the other parts of the cut.

Second group (maritime levels).—Work to be distributed over the last five or six years.

Third group (intermediate levels, excluding the central cut).—Work to be distributed over the first four or five years.

Fourth group (diversion channels between Bohio and the sea).—Work to be distributed over the last four years.

WORKS OF CONSTRUCTION (EXCLUDING THE BOHIO GROUP).

Pedro Miguel and Miraflores locks.—Work to be distributed over the first five years.

Obispo and Paraiso locks.—(If required) work to be distributed over the last six years.

Dams connected with the locks.—Work to be distributed over the last two years.

NOTE VII.—*General programme for the works of construction in the valley of the upper Chagres.*

The works in the valley of the upper Chagres peculiar to the project with the bottom at elevation 20.75 meters, favored by the technical commission, consist of—

The construction of the Alhajuela dam.

The construction of the feeder between this dam and the summit level.

The construction of a railroad between a bridge situated near Gamboa and Alhajuela, as a ready means of access and of transportation to the above-mentioned yards.

It is understood that if the 9.75-meter project is finally adopted, the feeder will not be required and the works on the upper Chagres will only consist in the construction of the dam and of the railroad intended to afford ready access to it.

The general programme proposed for the construction of all these works is subordinate to the object of each of them, to their respective urgency, and to the time required for construction.

It is evident that the building of the railroad must precede everything else, as it is intended to supply the needful facilities for building the other works. This railroad, about 16 kilometers long, does not involve any serious technical difficulty. The project for building it shows that it calls for only 170,000 cubic meters of earthworks and ordinary works of construction requiring in all 9,000 cubic meters of masonry. Under these conditions it may probably be built in about two years, and only after that can the dam be effectively undertaken. Only preparatory works can be undertaken previously.

ALHAJUELA DAM.

It will be advantageous to build the dam as rapidly as possible in order to make use of the power afforded by the fall; it should be undertaken from the third year. In order to facilitate its building it will be necessary to divert the waters of the Chagres by opening a tunnel about 300 meters long and having a cross section of 50 square meters at the low-water level of the river, through the rocky promontory of the left bank against which the dam is to abut. By building at a short distance below the head of this gallery a temporary dam, with a crest about 6.50 meters above the low-water stage of the river, the water will be diverted into it. The discharging capacity of the tunnel will be about 400 cubic meters per second when the water level rises to the crest of the temporary dam. It will be only by larger discharges than this that the dam can be flooded and the construction yards of the main dam be invaded.

This diversion of the Chagres must be completed before starting, except partially, on the foundations of the dam. It would be well, therefore, to undertake it without waiting till the railroad is finished. About a year will be required to complete it.

I stated at the ninety-fifth session of the technical commission how I would proceed with the construction of the dam, namely, by successive sections in height and by successive half sections in length. I shall not repeat that statement which was approved by the commission. I shall recall merely that, after the preliminary works have been completed during the first two years, the complete construction of the permanent works will require five years, making about seven years in all. During the same interval the waste weir connected with the dam will have been built.

METHOD OF CONSTRUCTION.

Here is presented a very interesting question connected directly with the programme of construction, namely, the method of construction of this dam. Generally speaking, it is to be built of concrete, as ordinary masonry in large masses is too difficult to be undertaken on the

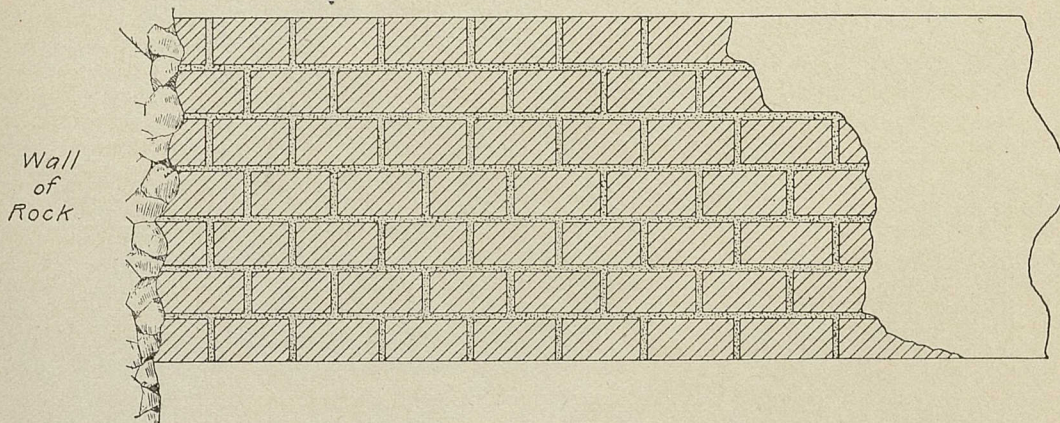


FIG. 11.

Isthmus. How are we to proceed with the construction of this mass? Two general methods may be considered. By one, concrete blocks manufactured on selected sites would be transported, when sufficiently set, to the dam and methodically placed in position.

These blocks would be disposed in regular courses leaving quite large intervals between them, to be filled later with concrete made on the spot, so as to form a perfect bond. Figure 11 illustrates the idea.

In the other method the concrete would be deposited in place in successive horizontal layers, about 1 meter high, developing into transversal blocks, which would unite naturally by the

manner of formation and thus would form a sort of monolithic mass constituting the dam. Figure 12 illustrates the progress of the work in a given horizontal section.

In each of these methods it would be useful to bind together all the horizontal layers, at least for a certain distance, starting at the upstream side, by means of strong iron cramps always anchored in two superposed layers. Thus would be counteracted perfectly any underpressures liable to occur should two horizontal sections lose their natural cohesion for want of adhesion of the concrete.

Each of these methods seems to me to have advantages and disadvantages which render it difficult to form an absolute opinion. The former would seem to promise a better manufacture of concrete which could be supervised more readily in the case of blocks fabricated at special sites. It has, however, the disadvantage of requiring the transportation of all materials to the block yards, which would necessarily be scattered, as they could not be located either in the vicinity of the places of delivery of materials or in the vicinity of the places for making use of the manufactured blocks. Thus it would be necessary to transport these blocks by railroad to the vicinity of the places making use of them, where they would have to be unloaded and again reloaded

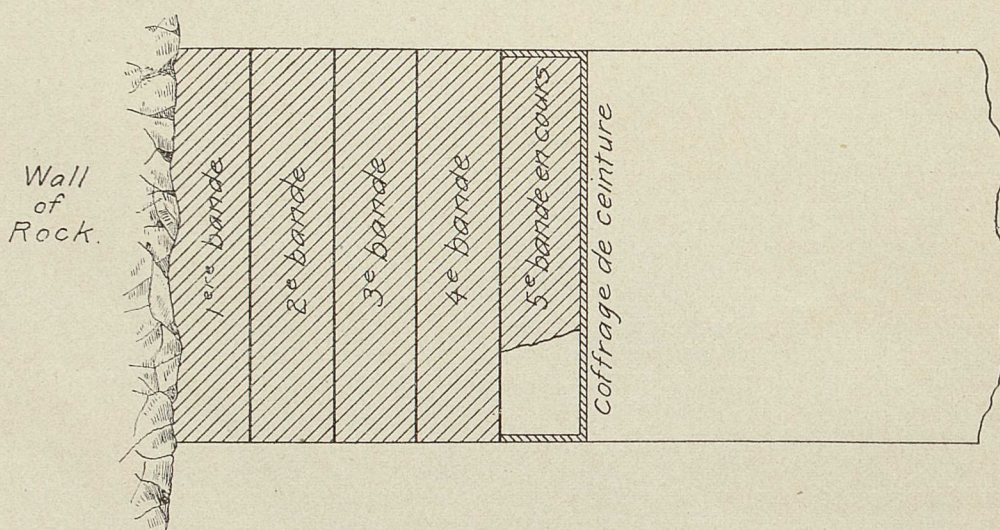


FIG. 12.

before being taken to their final destination. It is to be feared also that the manufacture as described above would not produce perfectly homogeneous material, and that internal cracks might form after the operation. The second method is more simple as regards installations and operations. An immense yard should be organized for supplies and for manufacturing concrete at a site in the vicinity of the dam. A site well suited for the purpose is found on the plateau where the proposed railroad terminates and where the elevation is only a few meters above the crest of the dam. It would lead doubtless to greater economy per cubic meter manufactured, and would have the advantage of compressing the bulk gradually and regularly, as the dam rises. The disadvantage would be the manufacture of great masses of concrete on a large scale, thereby making supervision difficult and uncertain, and the transportation of the material over a considerable distance from the manufacturing yards to the point for using it. This disadvantage might perhaps disappear by transferring the mixing of materials to the dam itself, the materials being brought as needed by means of aerial conveyances hung across and above the valley.

It is difficult to weigh justly the advantages and disadvantages of the two methods without taking into account local conditions likely to affect their application. These conditions can be exactly known only after a thorough study on the ground, at the time and in view of immediate operations. Judging from my general knowledge of the ground and from a theoretical appreciation of the two methods, I am inclined to think that the second method is the better and the more practical, if carried out with good judgment.

FEEDER.

The works of the feeder can be started only after the completion of the railroad, and consequently not before the third year. It would be logical and advisable to defer them as long as possible, only reserving sufficient time to complete them. In the next note, where I treat of labor and of its distribution, I shall show that six years are amply sufficient to complete this feeder. It would then suffice, arguing on the general basis of ten years, to begin work on the

feeder after the fourth year; and this date is in accord with the idea of reaching, only after four years' experience in the Culebra works, a final decision between the two projects at elevations 20.75 meters and 9.75 meters, the former, but not the latter, requiring a feeder. A certain margin for unexpected events should be allowed, and in any case work might be started after the third year at the risk of beginning works which would become useless should a decision be taken later rendering the feeder needless. In the next note, treating of labor, I reason on the supposition that the feeder will be begun as soon as practically possible, namely, after the third year. However, this is not material to the discussion of the programme of distributing these feeder works, since they may be transferred in block one year or two, according to convenience, when the time has come for undertaking them.

As to the programme of distributing the works of various kinds of this feeder over six years, which time will be ample to complete them, it should depend, in my opinion, on the consideration of reducing to a minimum the number of operatives to assign to it annually, and for that purpose to arrive at a yearly average as nearly constant as possible. Therefore I refer to the next note, which treats of labor, for settling this programme by determining the number of working days required for every class of works. Here I will state merely the results in anticipation. In adopting six years for completing this special work, the various classes of works should be distributed as follows:

The general earthworks, consisting of 620,000 cubic meters of earth or rock—over six years;

The fourteen tunnels, having a total length of 1,555 meters—over the first five years;

The various dams and masonry dikes across the secondary depressions which cut the feeder line, and which together amount to 29,000 cubic meters of masonry—during the fourth and fifth years;

The supports of the large siphons across the valley of the Chilibre—during the first and the second years;

The foundations of the other works of construction and their masonry parts—during the first four years.

As to the iron works proper, they will be prepared outside of the Isthmus, where the mounting only will be done. These works will require a small number of skilled mechanics who are not included in the studies I made concerning labor; the works will be completed readily in the last two years.

NOTE VIII.—*Studies concerning the total numbers of laborers and masons necessary per year for constructing the works included in the 20.75 meter project, and general distribution of yearly expenses.*

In the preceding notes I sought to elaborate a judicious programme for the distribution of the several classes of work embodied in the canal project adopted by the technical committee. The fundamental idea of these studies, outside of the technical requirements which a priori imposed on certain works appropriate periods of construction, was to arrive at a distribution as constant as possible of the labor necessary, thereby avoiding too marked variations which might result in calling for excessive numbers in certain years and thus make recruiting difficult. Moreover, it should be admitted a priori that the first two years will be a time for preparation and for organization, when far less than the general average number of operatives can be profitably employed. This fact accords with recruiting possibilities, which can be developed only gradually. It will be understood readily that the last year, during which finishing touches will be given and the yards gradually cleared, must also fall below the average.

It is advantageous to form at least an approximate idea of the practical results to be obtained in applying the resulting working programmes as to labor required. This study is the object sought in this note, which deals only with laborers and masons. The special mechanics to be employed at certain places will only play a very secondary part as to number, and their recruiting can not cause any trouble.

I need hardly say that the studies I have made can not lay claim to absolute certainty. They have an element of uncertainty which may always be argued pro and con—namely, the output of the operatives, taking into account their combination with machinery. Only experience in the future can give positive information on this matter. The experience of the past, together with the experience on other actual works, can furnish only approximate data, which may be considered as obtained under unfavorable conditions and thereby leading to maximum estimates. On the other hand, results obtained on somewhat similar works, but conducted in regions absolutely different as regards general conditions, can lead only to erroneous ideas which common sense should rectify. Nevertheless, with the help of all these data, and by adapting them to actual conditions, it is possible to reach a solution of the question approximately correct. The following study has this in view.

The total period of construction is assumed to be ten years, as explained in Note IV. The works will be distributed over these ten years, according to the following statement, which is a summary of the programmes of construction outlined in the preceding notes.

GENERAL EXCAVATIONS OF THE CANAL.

The general excavations of the canal are estimated at about 49,000,000 cubic meters, consisting of—

Dredgable excavations	Cubic meters. 13,000,000
Excavations in the dry	38,000,000

Adding about one-tenth for contingencies, we have—

Dredgable excavations	Cubic meters. 14,000,000
Excavations in the dry	40,000,000

The dredgable excavations will be made almost exclusively in the two maritime levels, and I have considered them as distributed over the last six years; as to the other excavations, they must be distributed over the total time as uniformly as possible. However, during the first year only a small estimate is made on account of the delays of organization, the output being assumed to be only one-fourth that of a normal year. For the second year the output will be about half that of a normal year. Finally, in the last year very little excavating will be left over, so much labor being devoted to revetment; hence only one-half of the output of a normal year is estimated.

From these data the output of a normal year in dry excavations would be 4,850,000 cubic meters, that of the first year being 1,250,000 cubic meters, that of the second and tenth years, respectively, being 2,500,000 cubic meters.

The yearly outputs to be anticipated are stated in the following table:

Years.	Estimate of excavations.		Effective number of laborers required each day.	Years.	Estimate of excavations.		Effective number of laborers required each day.
	With dredges.	In the dry.			With dredges.	In the dry.	
First year.....		1,250,000	2,230	Sixth year.....	2,350,000	4,850,000	9,720
Second year.....		2,500,000	4,460	Seventh year.....	2,350,000	4,850,000	9,720
Third year.....		4,850,000	8,670	Eighth year.....	2,350,000	4,850,000	9,720
Fourth year.....		4,850,000	8,670	Ninth year.....	2,350,000	4,850,000	9,720
Fifth year.....	2,350,000	4,850,000	9,720	Tenth year.....	2,250,000	2,500,000	5,460

In order to figure the number of working-days required, I will take as a basis of output for a working-day, taking into account the total number of laborers, 2 cubic meters in the dry and 8 cubic meters for dredgable excavations. Further, I assume two hundred and eighty real working-days in a year. The yearly production of each daily laborer will be—

For output in the dry	Cubic meters. 560
For dredgable excavations.....	2,240

The total number of daily laborers required will be found readily. It is stated in the fourth column of the preceding table.

As regards the 2 cubic meter basis for each laborer, as stated above, I will remark that in the extensive Chicago canal works, where machinery was used to a considerable extent, a production of 4 to 5 cubic meters for each working-day was reached in soils similar to those in question, but there was hardly any longitudinal transportation. During the recent excavations for a large reservoir in New York City the monthly production was 75,000 cubic meters with 800 men per day, all included, which makes 3.75 cubic meters for a working-day with an extensive use of machinery. On the Isthmus, all things being equal, I think these outputs should be reduced by half, considering the climate and the quality of labor.

WORK OF THE LOCKS.

The work for the locks, as far as excavations and masonry go, must be completed within the first nine years, the last being devoted to final installations of machinery. They will be distributed into two phases of five years each, the former from the first to the fifth, inclusive, the latter from the fifth to the tenth, exclusive. There will be simultaneous operations in two phases during the fifth year, its masonry being completed in the former, while excavations will be continued in the latter. Two years will be required in each phase for completing excavations.

The total estimate of these excavations is about 4,000,000 cubic meters distributed in the two phases about as follows:

	Cubic meters.
First phase.....	2,500,000
Second phase.....	1,500,000

Not over 1.50 cubic meters should be figured as the output of a working-day, or 420 cubic meters per year for each daily laborer. Accordingly, these excavations will require during the—

	Daily laborers.
First year.....	3,000
Second year.....	3,000
Third year.....	1,720
Sixth year.....	1,720

The masonry for all the locks amounts to 1,735,000 cubic meters. Their construction can be distributed very approximately over the seven years from the third to the ninth, inclusive, the output of the ninth being only half of a normal year. The yearly cubic estimates will be:

	Cubic meters.
Third year.....	267,000
Fourth year.....	267,000
Fifth year.....	267,000
Sixth year.....	267,000
Seventh year.....	267,000
Eighth year.....	267,000
Ninth year.....	133,000

Four operatives per day, of whom 1, a mason, and 3 ordinary laborers are required for 4 cubic meters of masonry, mainly concrete, it being understood that these 4 operatives take part in all the works, direct or indirect, such as supplying and breaking stones, supplying sand, mixing mortar, etc. The output of such a group of 1 mason and 3 ordinary laborers per day amounts to 1,120 cubic meters per year. On this basis is prepared the following table, showing the requirements as to labor for this masonry:

Year.	Daily require-ments.		Year.	Daily require-ments.	
	Masons.	Laborers.		Masons.	Laborers.
Third year.....	240	720	Seventh year.....	240	720
Fourth year.....	240	720	Eighth year.....	240	720
Fifth year.....	240	720	Ninth year.....	120	360
Sixth year.....	240	720			

The following table sums up the number of operatives necessary for the work of the locks:

Year.	Daily number of operatives.		Year.	Daily number of operatives.	
	Masons.	Laborers.		Masons.	Laborers.
First year.....		3,000	Sixth year.....	240	2,240
Second year.....		3,000	Seventh year.....	240	720
Third year.....	240	720	Eighth year.....	240	720
Fourth year.....	240	720	Ninth year.....	120	360
Fifth year.....	240	2,240	Tenth year.....	120	360

The preceding figures are based on the projected twin locks with chambers 25 and 18 meters wide. The company having decided to adopt equal chambers 25 meters wide, the foregoing figures must be altered, but not materially.

VARIOUS DAMS.

Separate consideration will be given to the Alhajuela dam, the Bohio dam and its waste weirs, and the remaining dams.

ALHAJUELA DAM.

The Alhajuela dam will be begun only at the third year and terminated at the seventh. Together with its accessory works, it requires about 220,000 cubic meters of excavations, 160,000 cubic meters of concrete masonry, and a tunnel 300 meters long through rock. The tunnel should be constructed in the second and third years; the excavations in the third and fourth years, and

the masonry during the third, fourth, fifth, sixth, and seventh years. Taking the same basis as for the locks, namely, 1.50 meters per working day for excavations, 4 cubic meters of masonry per day for one group of 1 mason and 3 laborers; and, finally, supposing the tunnel work to progress at 0.50 of a linear meter on a full section at each heading with a gang of 60 men per day—that is to say, 120 men will be required for a progress of 1 meter a day—the following results are reached:

Tunnel.—One hundred and twenty operatives per day for three hundred days, half in the second and half in the third year, or an average of 60 per day for the entire two years, of whom 10 will be masons and 50 ordinary laborers.

Excavations.—One hundred and ten thousand cubic meters per year, at the rate of 420 cubic meters for each daily laborer, which makes 260 daily laborers in the third and fourth years.

Masonry.—Thirty-two thousand cubic meters per year, at the rate of 1,120 cubic meters for 1 daily mason and 3 daily ordinary laborers, which makes 30 daily masons and 90 daily ordinary laborers in the third, fourth, fifth, sixth, and seventh years.

These results are summed up as follows:

Year.	Daily operatives.		Year.	Daily operatives.	
	Masons.	Laborers.		Masons.	Laborers.
Third year.....	40	400	Sixth year.....	30	90
Fourth year.....	40	400	Seventh year.....	30	90
Fifth year.....	30	90			

BOHIO DAM.

The dam and waste weirs at Bohio, together with the accessory works, will be executed in the second, third, fourth, fifth, sixth, and seventh years.

The concrete guard wall, amounting to 30,000 cubic meters, will be done in the third year, requiring 25 masons and 75 ordinary laborers per day. The cofferdam, consisting of piles and sheet piling, will have been finished the year before.

The body of the dam, to be almost completed in the next four years, consists of:

First. About 160,000 cubic meters of enrockments or dry masonry, or 40,000 cubic meters per year, in respect to which an output of not over 1 cubic meter per working day should be expected with 4 men (including all the men engaged in permanent or preparatory work), or 280 cubic meters per year with 4 men per day, or 70 cubic meters for each daily laborer. It follows that 570 men per day will be required for four years for this undertaking.

Second. An argillaceous embankment of about 350,000 cubic meters, to be completed during the same number of years, or 87,500 cubic meters per year, on which I figure only on an output of 1 cubic meter per day per man, including all the laborers engaged in the various duties required for this work, or 280 cubic meters per year for each daily laborer; which makes a total of 310 daily laborers during the four years in question.

As to the excavations for the dam and the waste weirs, amounting to 1,150,000 cubic meters, they will be distributed over the second, third, and fourth years—that is, 383,000 cubic meters per year—on which may be estimated an output of 2.50 meters per day and per laborer, or 700 cubic meters per year for a daily laborer, which calls for 550 daily operatives in the second, third, and fourth years.

These various results are summed up as follows:

Year.	Daily operatives necessary.		Year.	Daily operatives necessary.	
	Masons.	Laborers.		Masons.	Laborers.
Second year.....		550	Fifth year.....	25	980
Third year.....	25	625	Sixth year.....	25	980
Fourth year.....	25	1,430	Seventh year.....	25	980

REMAINING DAMS.

The remaining dams, including their waste weirs and outlets, comprise together 670,000 cubic meters of earthworks (excavations or embankments) and 24,000 cubic meters of masonry. They may be built in two years—in the eighth and ninth years. Figuring on the basis adopted before, we find that 10 masons and 620 ordinary laborers per day will be required during these two years.

All the above-stated results for the dams are summed up in the following table:

Year.	Daily operatives necessary.		Year.	Daily operatives necessary.	
	Masons.	Laborers.		Masons.	Laborers.
First year			Sixth year	30	1,070
Second year		550	Seventh year	30	1,070
Third year	65	1,025	Eighth year	10	620
Fourth year	40	1,830	Ninth year	10	620
Fifth year	30	1,070	Tenth year		

RAILROADS.

They consist of: (1) The Panama Railroad diversion; (2) the railroad of the upper Chagres.

Panama Railroad diversion.—This railroad, 50 kilometers in length, is estimated at 250,000 francs per kilometer, including about 150,000 francs per kilometer for works requiring ordinary laborers. As a basis for the number of laborers necessary (excluding specialized artisans), a daily laborer can be figured for every 1,000 francs of yearly expense. The ordinary works will be distributed over the second, third, fourth, fifth, sixth, seventh, and eighth years. Therefore the yearly expense will be about 21,400 francs a kilometer, or 1,070,000 francs in all, requiring on the foregoing basis 1,070 daily laborers, excluding the specialized men. Out of the 1,070 ordinary operatives there will be one-fifteenth of masons, or 70.

Railroad of the upper Chagres.—This railroad must be completed in two years; in the second year tracks will be laid and special works completed, while in the first the entire substructure will be finished. This work comprises about 175,000 cubic meters of various excavations for foundations or fills and 9,000 cubic meters of masonry for construction works. On account of the yards being scattered, it is proper to take a rather smaller basis than before in respect of the output of daily operatives. I shall adopt 2 meters for the earthworks and 2 cubic meters of masonry for 4 men, of which 1 is a mason. The number of days necessary to complete the foregoing works will then be:

For the earthworks, 87,000 days' work.

For the masonry, 4,500 days' work of masons, 13,500 days' work of ordinary laborers, and

Figuring on two hundred and eighty working days per year, we obtain:

For the earthworks, 310 laborers per day.

For the masonry, 16 masons per day and 54 laborers per day.

Finally, to complete the railroads, the following numbers of daily laborers are deemed necessary:

Year.	Laborers.	Masons.	Year.	Laborers.	Masons.
First year	370	20	Sixth year	1,000	70
Second year	1,000	70	Seventh year	1,000	70
Third year	1,000	70	Eighth year	1,000	70
Fourth year	1,000	70	Ninth year		
Fifth year	1,000	70	Tenth year		

FEEDER.

The principal works for the feeder, which require only ordinary laborers, are as follows:

First. General earthworks, with levees and dikes of earth.

Second. Tunnels.

Third. Dams and dikes of masonry.

Fourth. Foundation excavations and masonry for various works of construction, including large syphons.

I shall examine each in turn. Moreover, I assume that the feeder can be begun only after the railroad has been completed, and that it will take a maximum of six years after the completion of the railroad.

GENERAL EARTHWORKS.

The general earthworks comprise 619,000 cubic meters of excavations, which I increase to 700,000 cubic meters in consideration of contingencies. Admitting only two hundred and fifty working days per year, the yearly volume required being 117,000 cubic meters, the average output for a working day will be 470 cubic meters, and, figuring only on an output of 1.50 cubic meters per day for men employed at the yards, the number of men necessary will be 310.

The levees and earthen dikes, including the embankment in the Chilibre Valley, call for a total volume of 77,000 cubic meters, part of which will be derived from the excavations of the feeder. By distributing the execution of these works over a period of six years, the yearly volume required would be 13,000 cubic meters, and, figuring on two hundred and fifty working days per year and on only 1 cubic meter of output per man for one working day, the number of men necessary will be 50 per day.

TUNNELS.

The tunnels aggregate a length of 1,155 meters. In ordinary regions and under like conditions of execution, we may figure on an average progress in tunnels of 1 running meter per effective working day, with a gang of from 80 to 100 men at each heading. Only half of this output can be depended on here. Supposing, then, that work is begun at both ends only of a tunnel, and that one tunnel after another is worked—that is, only two points being attacked at the same time—the output would be 1 meter per day with from 160 to 200 men. We may admit here three hundred working days per year; hence an output of 300 meters per year, whereby the tunnels would be completed in five years and two months, under the most unfavorable conditions. The tunnels will require, therefore, a maximum of 200 men during five years.

DAMS AND MASONRY DIKES.

The total volume of masonry for all these works is about 30,000 cubic meters. I assume that their completion should be attempted within two years only. The yearly volume required will then be 15,000 cubic meters per year during two hundred and fifty working days, or 60 cubic meters per day. Figuring on an output of only 0.50 cubic meter per working day (including all the men engaged in these works), the number required will be 120 men per day.

FOUNDATION EXCAVATIONS AND MASONRY FOR VARIOUS WORKS OF CONSTRUCTION.

I shall examine separately the supports of siphons and the totality of the remaining works of construction.

The supports of syphons comprise about 50,000 cubic meters of excavations and 10,000 cubic meters of concrete for the supporting columns. Allowing two years only for preparing them—a year consisting of two hundred and fifty working days—and figuring only on an output of 2 cubic meters per working day for excavations and 0.50 cubic meter for concrete, the number required will be 100 men per day.

The whole of the remaining works of construction comprise 4,000 cubic meters of foundation excavations and 7,500 cubic meters of masonry. Their completion may be expected within four years, of two hundred and fifty working days each. Figuring on an output of 1 cubic meter per working day for excavations, and 0.50 cubic meter for masonry, the number required will be 20 men per day.

RECAPITULATION.

If the above works are constructed during the following intervals of time—

General earthwork in six years;

Tunnels in the first five years;

Dams and masonry dikes in the fourth and fifth years;

The supports of siphons in the first and second years;

The foundations of the remaining works of construction in the first four years—the maximum number of daily operatives required (exclusive of specialized laborers) will be as follows:

Year.	Masons.	Laborers.	Year.	Masons.	Laborers.
First year (of the entire period)			Sixth year	30	670
Second year			Seventh year	30	650
Third year		680	Eighth year .....	.....	480
Fourth year		680	Ninth year .....	.....	.....
Fifth year		580	Tenth year .....	.....	.....

DIVERSIONS AND WIDENING OF THE CHAGRES.

These works comprise about 5,500,000 cubic meters of excavations, to be distributed over the last four years, or 1,375,000 cubic meters per year. About half may be dredged, and an average output of 5 cubic meters per man per working day can be figured on, or 1,400 cubic meters per

year for each daily laborer. It follows that for 1,375,000 cubic meters per year 1,000 laborers per day are required. Therefore, the requirements are figured as follows:

Year.	Laborers per day.	Year.	Laborers per day.
First year		Sixth year	
Second year		Seventh year	1,000
Third year		Eighth year	1,000
Fourth year		Ninth year	1,000
Fifth year		Tenth year	1,000

WORKS NOT CONSIDERED.

The works not considered represent in the estimates about 0.08 of the cost of those considered. It may be assumed that part of these works, a third, for instance, need not be constructed until after the expiration of the time adopted to complete the canal. The remaining two-thirds, or 0.05, of the works considered, may be undertaken during the last four years. The only logical way to estimate the number of daily laborers required for these objects is to assume the total number of working days required to be 0.05 of the total of the works considered, and then to distribute it over four years, which makes, per year, 0.0125 of the whole of the works considered. Determined in this way, the number of operatives required is found to be 1,300 laborers and 30 masons during the last four years, as is exemplified in the following table:

Year.	Masons.	Laborers.	Year.	Masons.	Laborers.
First year			Sixth year		
Second year			Seventh year	30	1,300
Third year			Eighth year	30	1,300
Fourth year			Ninth year	30	1,300
Fifth year			Tenth year	30	1,300

The annexed table sums up the aggregate results reached. They are illustrated clearly to the eye on the graphical chart in the atlas accompanying this note (plate 17).

DISTRIBUTION OF ANNUAL EXPENSES.

The analysis of the distribution to be made of the totality of the works over the ten years of construction, contained in the preceding notes and the present note, renders it easy to establish logically the annual expenses which will result from an application of the programme, as well as the direct expenses of the works proper themselves. I shall not enter into any new details on this subject, and will limit myself to indicating, under the form of a summary table appended to this note, the results that have been reached. They are also shown in a clearer manner on the accompanying atlas (plate 17).

Paris, October 1, 1899.

CHORON,
The Director of Studies and Works.

Table summing up the numbers of daily operatives necessary to construct the project with a bottom elevation of 20.75 meters within ten years.

Classes of works.	Masons.									
	First year.	Second year.	Third year.	Fourth year.	Fifth year.	Sixth year.	Seventh year.	Eighth year.	Ninth year.	Tenth year.
General earthworks										
Works for locks			240	240	240	240	240	240	120	
Works for dams			65	40	30	30	30	10	10	
Railroads	20	70	70	70	70	70	70	70		
Feeder						30	30			
Diversions and widening of the Chagres										
Works not considered							30	30	30	30
Total	20	70	375	350	340	370	400	350	160	30

Daily averages in the total period, 246.

Classes of works.	Laborers.									
	First year.	Second year.	Third year.	Fourth year.	Fifth year.	Sixth year.	Seventh year.	Eighth year.	Ninth year.	Tenth year.
General earthworks	2,230	4,460	8,670	8,670	9,720	9,720	9,720	9,720	9,720	5,460
Works for locks	2,380	2,380	720	720	3,100	3,100	720	720	360	
Works for dams		550	1,025	1,830	1,070	1,070	1,070	620	620	
Railroads	370	1,000	1,000	1,000	1,000	1,000	1,000	1,000		
Feeder			680	680	580	670	650	480		
Diversions and widening of the Chagres							1,000	1,000	1,000	1,000
Works not considered							1,300	1,300	1,300	1,300
Total	4,980	8,390	12,095	12,900	15,470	15,560	15,460	14,840	13,000	7,760

Daily averages in the total period, 12,045.

APPENDIX B.

A DISCUSSION OF THE HYDRAULICS OF THE CHAGRES RIVER IN ITS RELATION TO THE PANAMA CANAL.

By Brig. Gen. H. L. ABBOT, U. S. Army.

Nature has interposed only two formidable engineering difficulties on the line of the canal—the cut at the Continental Divide and the regulation of the Chagres River. The latter has demanded investigations of the most elaborate character. Indeed it is by far the most important element to be considered, for upon the plan adopted will depend whether we are to have a good or a bad canal. The canal must follow the valley of the stream from Mindi to near Gamboa, a total distance of about 25 miles. Below Bohio it will have a different channel, but at so short a distance as to require protection in times of flood. Above Bohio the two form a single water route. Furthermore, as the Chagres must supply the water required to operate a canal with locks, it was necessary to determine with certainty whether it could be made to furnish the volume needful for the largest prospective traffic.

The records of the old company and of the liquidation period had contributed many valuable data as to the hydrography of the river during those years; but the New Company inaugurated a series of observations without precedent on any tropical river. They included continuous records of water level by self-registering tide gauges, frequent measurement of the discharge at all stages, daily rain records, and a collation of all known facts bearing on previous floods. Borings were multiplied at all sites favorable for the construction of dams and locks. Accurate level lines were run for scores of miles through the tangled forest to determine with precision the contours of projected reservoir lakes. In a word, nothing was omitted to permit the application of engineering science to every possible solution of the two hydraulic problems. Observations of this character have been in progress ever since the New Company undertook the work. Even to the date of transfer it continued to determine accurately the volume carried by the river at by-hourly intervals at the three governing stations and thus to verify its conclusions. In fine, the knowledge acquired respecting the Chagres River is probably more definite and exact than that respecting any river of its size in the United States, a fact which for students of river hydraulics adds technical interest to its study.

The river heads in the Cordillera de San Blas, which here forms the Continental Divide and separates its waters from the Pacific. Two principal branches constitute the stream; one, known as the Pequeni, heads only about 5 miles from the Atlantic coast near Porto Bello; the other, which takes the name Chagres, although contributing less water than the Pequeni, heads in a direction a little south of east from this point and at an approximate distance of about 20 miles. The branches unite about 8 miles by the channel (3 as the crow flies) above Alhajuela, where is located one of the gauging stations of the New Company, just below the projected dam site.

This upper basin of the Chagres, about 320 square miles in area, has been little explored, and the boundaries of its northern and eastern watersheds have never been traced. The region is covered with a dense forest of tropical vegetation, and the stream winds among low ridges believed not to exceed a thousand or fifteen hundred feet in height. For a few miles above Alhajuela the channel is bordered by limestone bluffs, passing below the stratified calcareous sandstone of the lower river, and often deeply undercut by the freshets of the torrential stream. The rock at a few localities is nearly white, and is sometimes worn into fantastic forms and draped by overhanging vegetation characteristic of the Tropics. Rapids are here much more frequent than in the lower river. Taken as a whole, few regions offer greater natural beauties.

The middle subbasin has an area of 130 square miles, and lies between Alhajuela and Gamboa where the river joins the route of the canal. The stream was traversed by the writer in a canoe in March, 1898, the water being about a foot above low-water stage. The total distance was about 11 miles, the width of the waterway being 100 to 300 feet, the channel depth about 3 feet, and the current ranging from 3 to 6 feet per second, giving a discharge of about 800 cubic feet. Eighteen rapids were counted, several of them requiring hard poling to surmount. The bed

presented one marked peculiarity not seen in rivers having a regimen less torrential—the bars differed widely in composition. Some were of pure sand, others of pebbles, others of rounded stones 3 inches or more in diameter; there was little or no intermixing of materials. Evidently this peculiarity is due to the frequent freshets of the rainy season, which differ materially in volume and velocity and hence in transporting power. The water was beautifully clear; but the banks, although often of rock or protected by vegetable growth, were occasionally of clay showing evidence of moderate caving in times of high water.

In the lower subbasin between Gamboa and Bohio (area, 250 square miles) the channel enlarges and the rapids in great part disappear. The caving banks increase in number, but, as the entire region will be flooded by the projected lake and thus be protected against erosion, this feature has no practical importance.

REGIMEN OF THE CHAGRES.

The fact that the Chagres above Gamboa is essentially a clear-water stream was so well understood by the engineers of the New Company that no observations to determine the amount of earthy matter carried in suspension were deemed necessary. Fortunately, in view of the reckless misstatements that have been made respecting this element of the problem, the Isthmian Canal Commission of 1899–1901 investigated the volume of sedimentary matter quantitatively both for the Chagres and for the San Juan River at Sabalos Station, near where it issues from Lake Nicaragua, and where naturally the water must be exceptionally pure. The results are presented for comparison in the first half of Table 1, the second half being added to show the corresponding total discharges of the rivers as indicated by the gaugings of the Commission.

Although these data are not reported in a unit permitting a comparison with similar observations on other streams, they make it evident that the volume of sedimentary matter, which will be carried in suspension to Lake Bohio, will have no practical importance. Whatever comes down will be deposited near the entrance, where it can easily be removed by dredging.

The method of measurement was the following:

The sample taken was allowed to settle for twenty-four hours, the clear water poured off, and another sample added to the remainder. The clear water was decanted; the next day another sample added, and so on, accumulating any sediment that remained, until it became a measurable quantity, when its depth was read on the graduated glass in which the settlement was made. This reading gives, of course, only the bulk of the loose mud, and not the dry solid matter. The relation between the mud and the dry matter, as determined by a series of experiments for a similar purpose, made on the Gila River, Arizona, was five parts of mud to one of dry material. This factor has therefore been used in reducing the results.

Assuming that the specific gravity of the “dry material” was that of the deposits made by the Chagres River, a little computation will show that the mean for the five rainy months indicates at Alhajucla 0.015 of 1 per cent of the volume of water, at Bohio 0.018 of 1 per cent, and at Sabalos Station 0.008 of 1 per cent. That of the Mississippi in floods is 0.088 and of the Ganges 0.098 of 1 per cent.

TABLE 1.—*Sedimentary matter.*

Month.	Solid matter in cubic yards at—			Total discharge in acre-feet.		
	Alhajucla.	Bohio.	Sabalos station.	Alhajucla.	Bohio.	Sabalos station.
1900.						
June.....	15,180	30,540	143,480	115,080	189,520	741,117
July.....		152,760	207,762		366,470	1,073,149
August.....	81,230	116,000	166,247	251,790	361,550	1,288,735
September.....	41,660	79,360	122,595	184,520	308,830	1,266,473
October.....	97,000		113,203	300,610		1,752,367

It is true that, in addition, some sand and gravel will be rolled along the bottom, but the volume will be unimportant, and the sedimentary matter, also, will be largely reduced if the precaution be taken to regulate the freshets as well as the floods by an upper lake at Alhajucla.

The tributary streams below Alhajucla, although insignificant in the dry season, carry considerable volumes at times during the rainy months, and are not without importance in the problem of regulation. Fifteen of them enter between Alhajucla and Gamboa and 17 thence to Bohio; and there are about 30 below. Several of them were gauged both by the company and by the Commission, but, as will appear below, the results need not be considered here in detail.

Not only have the level surveys of the two companies given precise information as to the slopes and more important contours of the valley above Bohio, but fluvio-graphs established at Gamboa in 1882, at Bohio before 1890, and at Alhajucla in 1899 have furnished a nearly con-

tinuous automatic record of river stages covering about twenty years. That at Gamboa, where the Chagres first joins the canal, was naturally regarded as the most important, and is the most complete.

The mean tidal oscillation at Colon, based on sixty months of daily observations between 1882 and 1887, is 1.43 feet, ranging from a maximum of 2.07 feet to a minimum of 0.62 foot. In extreme low water of the river the tidal level extends sensibly to Bohio, where a slight tidal oscillation of a few inches then appears. Ascending the river from this point the slope of the bed rises rapidly; and, as already stated, many rapids appear above Gamboa at low stages. They play an important part in the regimen of the stream, since they hold in reserve certain differences of level which, when the river rises, furnish an effective motive power to carry forward the increased volume, and thus reduce the oscillation between high and low water level. For example, the maximum variation noted during the past half century at Bohio was 39.4 feet, becoming at Gamboa about 37.7 feet, while at Alhajuela, although no authentic records are available, it could hardly have exceeded 18 feet. Relations like these can be better presented graphically than by tables, and attention is invited to Figure VI for details.

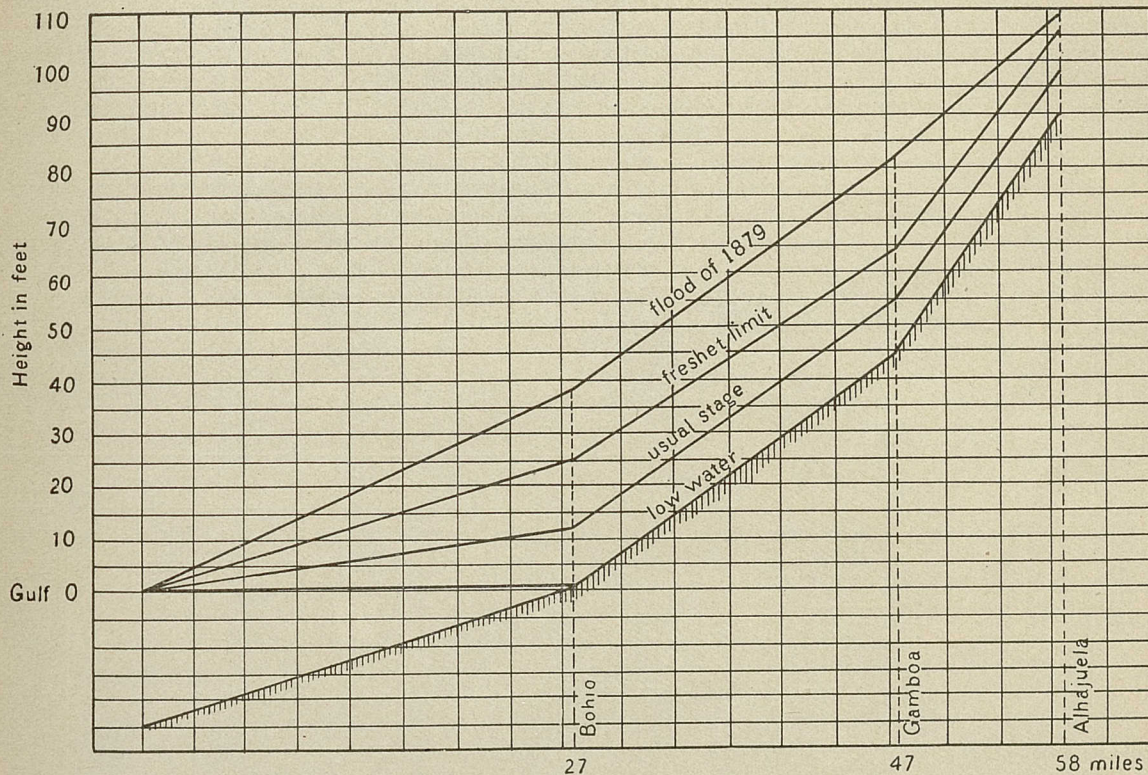


FIG. VI.—Chagres River, vertical longitudinal section.

As in all the rivers, there are considerable variations in the dimensions of the waterway at different localities near each other; but Table 2, giving those at the three gauging stations, may be considered to represent the channel fairly under normal conditions in the neighboring parts of the valley. In it "height" refers to elevation above mean tide level, and "velocity" to the maximum rate of flow as measured by surface floats following the thread of the current at the stages indicated.

The lowest water level of record occurred in April, 1901, being at Alhajuela 28 meters (91.86 feet), at Gamboa 13.72 meters (45 feet), and at Bohio 0.14 meter (0.46 foot) above mean tide. For convenience, the low stage at these three posts has been assumed as 28 meters, 14 meters, and 0 meter, respectively, the superior limit of usual stages being 30 meters, 17 meters, and 4 meters. It may be remarked here that as all the records and computations have been made in metric units some slight discrepancies may be noted in this paper, due to the transformation into English units involving the neglect of small fractions.

TABLE 2.—Cross sections.

River stage.	Alhajuela, sea 58 miles.				Gamboa, sea 47 miles.				Bohio, sea 27 miles.			
	Height.	Width.	Area.	Velocity.	Height.	Width.	Area.	Velocity.	Height.	Width.	Area.	Velocity.
	<i>Feet.</i>	<i>Feet.</i>	<i>Square ft.</i>	<i>Foot-sec.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Square ft.</i>	<i>Foot-sec.</i>	<i>Feet.</i>	<i>Feet.</i>	<i>Square ft.</i>	<i>Foot-sec.</i>
Low water.....	92	232	689	1.0	46	170	1,250	1.1	1	189	615	2.1
Usual stage.....	99	248	2,239	10.8	56	188	3,014	6.9	13	236	3,079	5.9
High freshet.....	107	284	4,661	12.1	70	(a)	(a)	14.1	26	288	6,362	7.9
Flood limit.....	110?	381	5,834	(?)	83	(a)	(a)	(?)	39	(a)	(a)	(?)

a Over bank.

The river year on the Isthmus is sharply divided, this being due to the marked variation in rainfall, which, inconsiderable in February, March, and April, increases in January and May, and is heavy in the seven other months. The great floods have always occurred in November or December. It is by a study of the very complete registers of the fluviograph at Gamboa that the regimen of the Chagres is best understood. The instrument was established there in 1882, and a nearly complete record has been kept since that date. It is lacking for the year 1889, when the old canal company ceased operations, and for some months in 1896 and 1897, for which the sheets were, unfortunately, lost. Thus nearly twenty years are available, and the chief difficulty is to arrange the important elements in the most compact form for examination. This is attempted in Table 3, which gives the number of times in each month that the river rose above 17 meters (the beginning of freshets, 10 feet above dead-low water); the total number of hours in each month that it remained above this level; the highest level attained in each month above dead-low water (14 meters); and, finally, for rough comparison, the local rainfall in inches. For a few months exact figures showing the greatest height attained above low water are not at hand, although the fact is of record that it did not reach the 17-meter stage; in such cases the word "less" will be found in the table. In computing means this word is given the average value for the years without rises.

TABLE 3.—Rises at Gamboa exceeding 10 feet above low-water stage, greatest height in feet above low water, and local rainfall in inches.

Year.	January.				February.				March.				April.			
	Rises.	Hours.	Feet.	Rain.	Rises.	Hours.	Feet.	Rain.	Rises.	Hours.	Feet.	Rain.	Rises.	Hours.	Feet.	Rain.
1882.....												0.5				1.5
1883.....	0	0	7.3		0	0	2.3		0	0	2.0		0	0	3.1	2.6
1884.....	0	0	5.7		0	0	3.3	0.7	0	0	2.4	0.3	2	9	12.6	6.5
1885.....	0	0	3.3	0.2	0	0	3.1	0.2	0	0	2.9	0.0	0	0	3.9	1.4
1886.....	0	0	7.3	0.5	0	0	4.8	1.1	1	9	12.8	0.7	0	0	8.2	2.8
1887.....	0	0	8.2	2.2	0	0	4.9	0.1	0	0	3.9	0.3	0	0	3.6	6.8
1888.....	0	0	5.1	0.1	0	0	3.3	0.6	0	0	3.0	0.4	1	10	13.1	1.3
1890.....	0	0	9.1	4.1	0	0	Less.	0.3	0	0	Less.	2.4	0	0	6.3	3.0
1891.....	0	0	Less.	0.6	0	0	Less.	0.0	0	0	Less.	0.3	0	0	Less.	2.1
1892.....	0	0	Less.	1.1	0	0	Less.	0.7	0	0	Less.	2.6	0	0	Less.	4.7
1893.....	0	0	3.0	0.7	0	0	3.6	1.1	0	0	6.3	0.7	2	27	16.3	7.4
1894.....	2	25	17.9	1.5	0	0	2.2	0.2	0	0	1.0	0.1	0	0	2.4	1.3
1895.....	1	2	10.3		0	0	2.4		0	0	2.3		1	1	10.0	
1896.....	0	0	4.9		0	0	Less.		0	0	Less.		0	0	8.5	
1897.....	0	0	7.2		0	0	Less.	0.2	0	0	Less.	0.3	1	3	10.2	3.2
1898.....	2	22	17.0	2.8	0	0	2.0	0.1	0	0	1.6	0.0	1	16	17.7	1.4
1899.....	2	29	14.2	5.0	0	0	Less.	1.7	0	0	Less.	1.3	0	0	5.3	1.4
1900.....	0	0	8.9	1.0	0	0	1.4	0.2	0	0	0.2	0.1	0	0	6.3	3.2
1901.....	0	0	3.2	0.4	0	0	2.4	0.2	0	0	1.0	0.2	0	0	2.3	0.8
1902.....	3	57	16.4	13.4	0	0	2.2	0.2	0	0	0.9	4.4	1	5	11.2	9.5
1903.....	0	0	2.4	0.7	0	0	4.1	0.1	0	0	0.6	0.3	0	0	1.3	0.4
1904.....	1	7	14.0	3.4	0	0	5.5	0.2	0	0	2.3	1.9	2	6	11.5	12.0
Mean...	1	7	8.4	2.4	0	0	3.6	0.4	0	0	2.5	8.8	1	4	7.7	3.7

TABLE 3.—*Rises at Gamboa exceeding 10 feet above low-water stage, greatest height in feet above low water, and local rainfall in inches—Continued.*

Year.	May.				June.				July.				August.			
	Rises.	Hours.	Feet.	Rain.	Rises.	Hours.	Feet.	Rain.	Rises.	Hours.	Feet.	Rain.	Rises.	Hours.	Feet.	Rain.
1882.....				15.5				6.3				10.1				9.9
1883.....	1	10	16.7	9.7	2	14	14.1	11.0	4	37	16.7	6.5	5	43	13.8	15.9
1884.....	3	137	16.1	6.2	5	29	16.7	13.4	4	49	17.7	9.6	3	25	15.1	16.5
1885.....	0	0	5.9	11.1	1	2	10.2	10.4	6	41	16.4	9.1	8	66	18.0	15.5
1886.....	0	0	9.5	15.7	2	10	11.8	10.6	5	31	15.1	11.7	5	28	11.8	16.4
1887.....	6	54	16.1	11.0	11	108	24.0	19.5	3	21	15.4	14.0	11	130	16.4	19.2
1888.....	0	0	8.2	20.5	6	43	14.8	11.9	0	0	Less.	3.3	1	7	12.2	10.2
1889.....	5	44	13.8	13.3	4	26	13.1	11.7	4	34	14.8	10.4	7	45	13.1	15.4
1891.....	2	15	14.1	7.5	1	10	14.8	9.3	2	18	16.1	6.1	0	0	Less.	8.5
1892.....	7	49	17.4	16.8	1	6	12.1	8.5	8	65	16.7	14.0	3	28	16.1	14.3
1893.....	2	23	16.4	11.9	0	0	5.9	10.7	1	5	11.8	15.9	2	13	13.9	8.0
1894.....	1	5	10.9	10.9	0	0	6.9	8.8	4	26	13.8	10.1	2	9	11.8	8.4
1895.....	0	0	2.3		1	12	15.9		1	13	13.7		2	6	12.9	
1896.....				3.4				3.3				5.8				
1897.....	6	96	23.0	17.4	0	0	8.9	12.6	0	0	9.7	9.1				17.2
1898.....	0	0	7.5	5.3	0	0	8.6	4.7	1	7	12.6	18.4	2	6	10.3	20.1
1899.....	2	15	13.5	8.5	1	2	10.1	8.8	1	1	10.1	9.5	2	23	16.2	11.0
1900.....	0	0	9.1	6.8	0	0	7.5	12.2	2	12	11.6	13.4	3	16	13.5	8.9
1901.....	1	8	13.4	10.9	1	1	10.1	7.7	0	0	8.2	9.2	2	5	10.3	13.9
1902.....					0	0	6.4	6.3	1	1	10.1	6.3	1	10	15.1	8.3
1903.....	0	0	5.7	11.1	1	2	10.1	11.1	1	14	18.7	13.5	1	7	16.1	12.9
Mean..	2	25	12.2	11.2	2	14	11.2	10.0	3	20	13.6	10.3	3	26	13.6	13.2

Year.	September.				October.				November.				December.			
	Rises.	Hours.	Feet.	Rain.	Rises.	Hours.	Feet.	Rain.	Rises.	Hours.	Feet.	Rain.	Rises.	Hours.	Feet.	Rain.
1882.....				11.8				8.2	8	104	18.4	11.8	0	0	Less.	1.4
1883.....	4	53	14.1	4.1	1	2	10.2	10.0	1	10	11.8	7.0	3	32	15.4	6.3
1884.....	3	21	13.8	10.5	5	42	15.4	22.4	2	31	19.0	6.2	0	0	6.9	2.2
1885.....	7	67	18.0	16.1	6	54	11.8	9.3	2	52	31.5	13.2	7	155	23.9	11.0
1886.....	5	48	15.1	9.1	9	92	15.4	13.6	13	156	17.1	16.1	4	72	15.8	4.6
1887.....	2	55	23.3	11.5				14.9	4	154	18.7	24.1	2	127	15.4	12.7
1888.....	10	78	15.4	12.3	5	27	12.5	9.6	3	20	10.5	16.2	4	424	31.4	16.3
1889.....	3	27	16.1	8.9	5	49	17.4	21.4	3	30	16.1	9.9	3	53	31.8	4.3
1891.....	0	0	Less.	10.5	1	1	10.2	15.7	2	54	19.7	10.7	2	18	12.8	6.4
1892.....	0	0	6.9	13.7	2	17	13.1	11.1	1	30	22.8	10.2	2	74	15.8	6.6
1893.....	0	0	9.2	10.2	0	0	8.9	16.5	1	9	13.1	13.9	6	170	25.3	20.9
1894.....	3	20	13.9	15.2	3	19	12.5	15.3	5	35	14.1	10.7	7	149	19.0	8.3
1895.....	0	0	8.9		2	22	17.1		0	0	8.5		1	1	10.0	
1896.....													1	15	13.3	
1897.....				18.8	1	2	10.2	12.8	3	16	12.7	5.9	4	37	13.2	8.6
1898.....	0	0	5.6	4.1	2	13	13.7	8.7	3	25	16.9	14.6	0	0	4.5	2.4
1899.....	0	0	8.6	13.5	0	0	9.8	8.0	2	16	14.8	8.7	0	0	9.4	2.7
1900.....	1	4	11.2	9.3	3	24	15.1	12.1	2	14	11.9	10.7	1	14	14.1	0.8
1901.....	1	6	11.7	8.4	0	0	9.5	14.1	7	73	20.9	19.1	1	14	15.4	6.7
1902.....	0	0	7.3	8.9	2	15	16.4	12.9	1	7	11.8	14.4	0	0	6.1	2.2
1903.....	0	0	8.3	9.3	0	0	9.0	14.2	3	48	20.3	11.9	6	23	13.0	13.9
Mean..	2	21	12.0	10.9	3	21	12.7	13.2	3	44	16.5	12.4	3	66	15.2	7.3

This tabular exhibit warrants important conclusions which will be confirmed by the tables of discharge. February and March are the extreme low-water months, the river then rarely rising more than 3 feet above the lowest stage. January and April are similar, although small freshets sometimes occur, especially in January. The other months show slight differences among themselves, but are all characterized by freshets, averaging about three per month, but sometimes exceeding ten. They are of very short duration, the river rarely remaining above the 17-meter stage for four days in an entire month, and rising and falling rapidly. Nevertheless, these freshets deliver considerable volumes of water, moving with high velocity and sweeping down the channel like great waves. The fluviograph records have enabled the rate of movement of their crests to be accurately noted; they traverse the 11 miles from Alhajuela to Gamboa in about four hours, and the 20 miles thence to Bohio in about six and one-half hours—indicating a rate of movement of about 4.5 feet per second, which of course is much less than that of the water itself. As will appear further on, investigations have shown that the interval of time which elapses between the heavy downpour of rain that causes a freshet and the arrival of its crest at Bohio varies from twenty-four to forty-eight hours, according to the locus of the storm. These facts make it evident that, with the system of telegraphic communication which will be demanded to operate the canal, an agent at adjustable waste weirs on Lake Bohio would have ample warning, and could judiciously regulate the level of that lake from what he could see before him.

It should be understood that these freshets, notwithstanding their short duration, are the controlling feature in the monthly discharge, the volume carried sometimes increasing ten and even twenty times as they pass. Bearing this in mind, the following annual summary, covering

the eight rainy months in Table 3 establishes the fact that there are considerable and progressive variations from year to year in the discharge; that during the operations of the old company the volume was excessive, culminating in 1886 and 1887; and that since that maximum it has diminished, apparently reaching a minimum in 1898 and 1899. Data for accurate estimates of discharge do not exist prior to 1890, and therefore this evidence of annual variation covering several years is presented here in the form of a summary of freshets at Gamboa. That the same condition affects Lake Nicaragua has been conclusively shown by the Isthmian Canal Commission of 1899–1901; and a study of the rain record at Colón, nearly complete since 1862, leads to the same conclusion.

Year.	Number of freshets.	Above 17 meters.	Local rainfall.	Year.	Number of freshets.	Above 17 meters.	Local rainfall.
		<i>Hours.</i>	<i>Inches.</i>			<i>Hours.</i>	<i>Inches.</i>
1883.....	21	201	70.5	1895.....	7	54	.....
1884.....	25	334	87.1	1897.....	14+	151+	102.5
1885.....	37	437	95.7	1898.....	8	51	78.3
1886.....	43	437	97.8	1899.....	8	57	70.5
1887.....	39+	649+	126.9	1900.....	12	84	74.2
1888.....	29	596	100.3	1901.....	13	107	90.0
1890.....	34	308	95.2	1902.....	5+	33+	59.3+
1891.....	10	116	74.6	1903.....	12	94	97.9
1892.....	24	269	95.3				
1893.....	12	220	107.9	Mean.....	20	235	89.5
1894.....	25	263	87.6				

The fact that the Chagres is now passing through a low-water epoch is so important in connection with the water supply of the canal that it becomes a matter of interest to push the inquiry further. This may be done by considering the data of Table 3 in six-year epochs, as is done in Table 4, taking into account the different months. These six-year epochs are all complete, except for the river data in October, 1887, and May, 1902; and for local rainfall for the year 1895, for January, February, and March, 1883, for January, 1884, and for May, 1902. The sign + following a figure in the table indicates that one month is missing, and, hence, that approximately one-fifth part should be added when comparing it with other months. This correction has been made in the averages.

TABLE 4.—Number and duration of freshets at Gamboa, with corresponding local rainfall.

Month.	Totals in 1883–1888.			Totals in 1890–1895.			Totals in 1898–1903.			Average freshet hours in six years.
	Freshets.	Hours.	Rainfall.	Freshets.	Hours.	Rainfall.	Freshets.	Hours.	Rainfall.	
January.....	0	0	3.0+	3	27	8.0+	7	108	23.3	45
February.....	0	0	2.7+	0	0	2.3+	0	0	2.5	0
March.....	1	9	1.7+	0	0	6.1+	0	0	6.3	3
April.....	3	19	21.4	3	28	18.5+	2	21	16.7	23
May.....	10	201	74.2	17	136	60.4+	3+	23+	42.6+	122
June.....	27	206	76.8	7	54	49.0+	3	5	50.8	88
July.....	22	179	54.2	20	161	56.5+	6	35	70.3	125
August.....	33	299	93.7	16	101	54.6+	11	67	75.1	156
September.....	31	322	63.6	6	47	58.5+	2	10	53.5	126
October.....	26+	217+	79.8	13	108	80.0+	7	52	70.0	126
November.....	25	423	82.8	12	158	55.4+	18	183	79.4	255
December.....	20	810	53.1	21	465	46.5+	8	51	28.7	442
Total.....	203	2,728	608.5	118	1,285	595.0	68	560	527.7	1,511
Annual.....	34	455	101.6	20	214	99.2	11	93	88.0	252

It should not be forgotten in comparing these three groups that the first includes two flood years (1885 and 1888) and the second two flood years (1890 and 1893), while the third has none; but as these floods affect only the months of November and December, the evidence is still conclusive that the third is a period of exceptionally low water, caused by a rainfall below the general average. The investigations of the Isthmian Canal Commission of 1899–1901 have demonstrated that similar variations covering several years have occurred in Nicaragua, but there seems to be no annual correlation between the two districts.

As currents, and especially cross currents from tributaries, are a very serious annoyance to a large vessel transversing a contracted channel, these freshets are worthy of careful study. This will be given below under a separate heading, after considering the mode of determining the volume carried by the river. The necessity of regulating the freshets, as well as the great floods, has been too much underrated.

DISCHARGE OF THE CHAGRES.

A trustworthy and safe valuation of the discharge of the river is naturally a matter of first importance in studying the project for a canal, and measurements were by no means neglected by the engineers of the old company; but when the work came under the control of the liquidator, and later under the New Company, a more systematic plan was put into operation. Detailed instructions were issued in September, 1889, defining the method to be followed, and it continued in force up to the end.

The location was carefully covered by seven transverse lines of soundings in parallel planes about 10 meters apart, which were frequently repeated to detect possible changes in the bed. Surface floats offering little resistance to the air, like bottles ballasted with water, were used to determine the velocity. They were started from a boat far enough above the base, from 60 to 80 meters long, according to locality, to attain it with the full velocity of the water. The times of transit were noted to quarter seconds by the observer with the watch, the instants of passing the ranges being called out by the other observer who preceded the floats. Six transits were usually noted, two at the middle of the stream and the others about half way to the banks. Full reports, including water level at the fluviograph and every detail, were submitted. The discharge was estimated by taking eight-tenths of the product of the mean velocity, as measured, by the area of cross section. Since 1889, with but few intermissions, the discharge has been thus measured at three-day intervals, and more frequently in times of freshets, at Gamboa and Bohio. Daily measurements were made at Alhajuela in 1895 and 1896, and since April, 1899, when they were resumed. During the last few years occasional night observations were attempted to secure additional determinations of the velocity in large freshets.

In considering this method of gauging, the problem before the engineers of the company should be borne in mind. The vital question was to determine whether the Chagres will supply all the needs of the canal in the season of low water. Any reasonable doubt here would be fatal to the project of a canal with locks, and no overestimate of discharge could be tolerated. Hence the adoption of the coefficient eight-tenths, when nine-tenths would probably accord more nearly with the fact. The value was certainly safe and conservative, and in the plans for flood regulation due allowance for its probable insufficiency was made.

It remains to consider how from these numerous gaugings to determine the volume carried by the river in stated periods—the monthly and yearly discharges, for example. The most obvious manner is to adopt the mean of all the daily measurements as the true mean for the period in question. The objections to this plan for a river so variable as the Chagres are apparent. Ten days per month are too few for a correct average, especially as freshets by night escape measurement, thus unduly reducing the numerical mean. On the other hand, the comparatively few gaugings during a freshet, when the discharge is undergoing almost momentary variation, are likely to furnish too large a volume, from the natural tendency to multiply observations at the higher levels, thus unduly increasing the numerical mean. Furthermore, as direct gaugings were not made in the great flood of 1879, the greatest of record and therefore the true standard for estimating the provisions needful for regulation, it becomes necessary to infer logically the true discharge at stages considerably above any actually measured. It is evident from these considerations that the problem can be solved in a satisfactory manner only by applying to the hourly stages, known from the fluviograph sheets, a rating table derived from the very numerous gaugings made between lowest and highest river stages.

The construction of a trustworthy rating table for a torrential river like the Chagres is by no means a simple problem. In all rivers the discharge at a given stage is always greater when the water is rising than when falling, owing to the greater local slope affecting the flow. To represent the river truly, the rating table must take account of this law by indicating the mean between the rising and falling branches of the curve, and this the mean of so many measurements will correctly represent. Such tables are often constructed by drawing an arbitrary line to reproduce as accurately as possible the average of the platted observations; but when it is needful, as in the present case, to extend the curve beyond the limit of the observations, the general law of its curvature should be studied and represented by a formula, thus extending this law to the unknown portion and eliminating arbitrary assumptions. As this unknown portion was less than 10 per cent of the whole curve at Gamboa and less than 20 per cent at Bohio, it is safe to assume that the predicted maximum discharge can involve no serious error. In framing the formula either the method of least squares or the method of algebraically compelling the curve to pass through the largest possible number of the best determined points may be employed, but as the relative weight to be accorded to the higher observations was not easily estimated the latter usually was preferred. The following formulæ finally resulted from the study, based for Gamboa on 2,147 gaugings, for Bohio on 1,854 gaugings, and for Alhajuela on 1,599 gaugings. In them

Q denotes the discharge in cubic meters per second and C the height of the water level above mean sea level in meters.

(1) Alhajuela:

$$Q = -6 + 52(C - 27.5)^2 - 1.6(C - 27.5)^3$$

(2) Gamboa^a:

$$Q = -24 + 24(C - 13) + 18(C - 13)^2 - 0.5(C - 13)^3$$

(3) Bohio:

$$Q = 47C + 5C^2 + C^3$$

The accordance between these formulæ and the observations from which they were derived left nothing to be desired for the general case, but to estimate the hourly discharge during the rapid oscillations of the river some further refinement was found to be necessary.

For a great river like the Mississippi, where the general water level changes from month to month, and where consequently the rises start from very different levels at different seasons, the problem becomes complex; but for a river like the Chagres, which between freshets always subsides to a comparatively low and little varying level, advantage may be taken of the fact by grouping the freshets for separate study, and thus investigating the influence on the discharge exerted by the rapidly varying local slopes, then so different from the condition in the great floods, when, the whole channel being surcharged, the slope from hour to hour usually remains comparatively constant. This study was carefully made, the ample data permitting the selection of gaugings taken only at periods of rapid changes of water level, when the object sought, the mean line between the rising and falling branches, could be accurately recognized. Very many such freshets were studied; and not only was it found that accordant values resulted at each separate locality, but that they could be well represented at Gamboa and Bohio by simply increasing in a nearly equal proportion the coefficients of the first power of the water-level term in the respective general formulæ. These special freshet formulæ, thus deduced, are the following, the variables having the same signification as before:

(4) Alhajuela:

$$Q = -7 + 110(C - 28) + 40(C - 28)^2 - 1.8(C - 28)^3$$

(5) Gamboa:

$$Q = -26 + 40(C - 13) + 18(C - 13)^2 - 0.5(C - 13)^3$$

(6) Bohio:

$$Q = 62C + 5C^2 + C^3$$

In fine, the method adopted to determine the continuous discharge of the Chagres since January, 1898, and for previous dates when the bihourly fluvigraph readings are at hand, has been the following:

When the river is at a stand, or changes its level gradually, the above general formulæ are used, or rather the rating tables derived from them. When a freshet occurs and the stream begins to rise rapidly, the special formula table takes its place until the original level is approximately regained, reference being made to any actual gaugings available in case of uncertainty as to which formula should be used, an uncertainty which in practice hardly occurs, so pronounced are the changes of level in the Chagres. If space permitted the reproduction of the very numerous tables of bihourly discharge at the three most important localities in the valley, each value based on wholly independent data, their uniform conformity to the known conditions would leave no doubt as to their accuracy. Indeed, on one occasion a small clerical error in the tabulated bihourly fluvigraph readings at Gamboa, received from the Isthmus, was detected from the resulting discrepancies in discharge as compared with that at Alhajuela and Bohio. The daily average values at the three posts are thus shown by internal evidence to be relatively correct, and any absolute uncertainty, due to the use of the coefficient eight-tenths in reducing the original gaugings, must affect them equally. As such error, if any exists, lies on the side of safety, the figures may certainly be accepted for purposes of canal regulation. Few hydraulic data are better established.

As will appear in the discussion of the water-supply problem, a knowledge of the average monthly flow of the river at Alhajuela, Gamboa, and Bohio is of capital importance. At Gamboa direct observations have made the monthly volumes known with precision ever since the date of the collapse of the old company, and the same is true at Bohio, since May, 1893. Unfortunately observations at Alhajuela were deferred to a later date, and it therefore became important to make a systematic study of the ratios between the corresponding discharges actually measured at the three stations in order to be able to supply missing months by transferring the volume measured at Gamboa. In the earlier studies this was done to a limited extent by making use of

^aFrom gaugings at dead low water the discharge at 13.7, 13.8, 13.9, and 14 meters is estimated at slightly increased figures; that is, at 10, 12, 15, and 19 cubic meters per second, respectively.

provisional ratios, but since the work terminated the writer has submitted all existing data to analysis, with results, it may be added, which differ but slightly from those provisionally adopted long ago by the engineers of the New Company. There were available for comparison 79 measured monthly discharges at Alhajuela, 169 at Gamboa, and 137 at Bohio. The percentages resulting from the analysis, with their probable errors, the latter in this case representing the effect of variations in the location of rainfall at the different dates, may be stated as follows:

The volume passing Alhajuela is 82 ± 2.1 per cent of that passing Gamboa in the dry season, 76 ± 1.4 per cent in the rainy season, and 79 ± 1 per cent annually.

The volume passing Alhajuela is 71 ± 2.7 per cent of that passing Bohio in the dry season, 51 ± 1.5 per cent in the rainy season, and 55 ± 1.4 per cent annually.

The volume passing Gamboa is 86 ± 2 per cent of that passing Bohio in the dry season, 65 ± 1.6 per cent in the rainy season, and 68 ± 1.4 per cent annually.

It is by the aid of these ratios that have been supplied the missing months in the following table showing the mean monthly discharge, in cubic feet per second, for over fourteen consecutive years at the three gauging stations. Such months are indicated by italic type. The values for January, 1890, and May, 1902, are interpolations, being the means of all months of same name at the stations. The other values are determined in the manner explained above, except when for a few of the earlier months fluvigraph records are lacking. In such cases the figures have been found by averaging the actual gaugings. It may be added that a comparison of the two methods covering many months has demonstrated that the causes of error in the latter largely balance each other in practice, and that important discrepancies are rare.

TABLE 5.—Mean monthly discharge in cubic feet per second.

AT ALHAJUELA.

Month.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	Mean.
January.....	2,190	<i>1,554</i>	<i>1,165</i>	<i>1,731</i>	<i>2,825</i>	<i>2,684</i>	2,437	<i>1,342</i>	<i>3,284</i>	<i>2,684</i>	1,589	989	4,238	1,130	3,002	2,190
February.....	<i>1,095</i>	<i>777</i>	<i>918</i>	<i>1,660</i>	<i>1,342</i>	<i>1,236</i>	1,059	<i>918</i>	<i>1,236</i>	<i>777</i>	812	671	1,271	848	1,589	1,081
March.....	<i>918</i>	<i>494</i>	<i>812</i>	<i>1,024</i>	<i>777</i>	<i>742</i>	600	<i>424</i>	<i>600</i>	<i>777</i>	530	459	812	494	954	695
April.....	<i>1,024</i>	<i>424</i>	<i>1,695</i>	<i>2,402</i>	<i>600</i>	<i>918</i>	1,271	<i>563</i>	<i>1,519</i>	<i>883</i>	565	459	1,695	565	2,190	1,118
May.....	<i>3,249</i>	<i>2,649</i>	<i>4,203</i>	<i>2,331</i>	<i>1,059</i>	<i>1,483</i>	<i>2,543</i>	<i>2,507</i>	<i>1,872</i>	<i>1,589</i>	1,342	1,554	2,119	1,377	.....	2,134
June.....	<i>4,061</i>	<i>1,801</i>	<i>2,649</i>	<i>2,437</i>	<i>1,695</i>	<i>2,048</i>	<i>2,225</i>	<i>1,801</i>	<i>2,190</i>	<i>2,154</i>	1,554	1,731	2,190	1,942	.....	2,177
July.....	<i>4,097</i>	<i>2,861</i>	<i>5,651</i>	<i>2,719</i>	<i>3,390</i>	<i>1,801</i>	<i>2,225</i>	<i>2,861</i>	<i>3,143</i>	<i>2,225</i>	2,190	1,978	2,119	3,108	.....	2,883
August.....	<i>4,309</i>	<i>2,119</i>	<i>4,626</i>	<i>3,602</i>	<i>2,967</i>	<i>2,543</i>	<i>2,145</i>	<i>3,108</i>	<i>3,143</i>	<i>3,284</i>	2,825	2,437	2,331	3,178	.....	3,044
September.....	<i>5,191</i>	<i>2,296</i>	<i>3,320</i>	<i>2,967</i>	<i>3,390</i>	<i>1,907</i>	<i>2,154</i>	<i>2,931</i>	<i>1,907</i>	<i>2,402</i>	2,154	2,931	2,366	2,790	.....	2,765
October.....	<i>4,909</i>	<i>3,390</i>	<i>4,521</i>	<i>2,896</i>	<i>3,567</i>	<i>3,638</i>	<i>2,048</i>	<i>2,931</i>	<i>2,649</i>	<i>2,649</i>	3,214	2,755	3,214	2,755	.....	3,224
November.....	<i>3,002</i>	<i>5,686</i>	<i>5,509</i>	<i>3,461</i>	<i>4,980</i>	<i>2,543</i>	<i>2,472</i>	<i>3,390</i>	<i>3,885</i>	<i>2,931</i>	2,967	4,768	3,143	4,009	.....	3,832
December.....	<i>4,485</i>	<i>3,885</i>	<i>4,627</i>	<i>6,110</i>	<i>8,088</i>	<i>3,920</i>	<i>3,885</i>	<i>3,532</i>	<i>1,731</i>	<i>2,260</i>	2,296	3,037	1,836	5,474	.....	3,940
Year.....	3,211	2,328	3,308	2,778	2,890	2,122	2,089	2,192	2,263	2,051	1,837	1,981	2,278	2,381	.....	2,424
Three dry.....	1,012	565	1,142	1,695	906	965	977	635	1,118	812	636	530	1,259	636	1,578	965
Rainy.....	3,944	2,917	4,030	3,139	3,551	2,507	2,459	2,711	2,645	2,464	2,237	2,453	2,617	2,963	.....	2,910

AT GAMBOA.

January.....	2,755	2,048	1,519	2,296	3,708	3,532	2,225	1,766	4,309	3,496	1,695	1,024	5,227	1,625	4,132	2,757
February.....	<i>1,842</i>	<i>954</i>	<i>1,095</i>	<i>2,013</i>	<i>1,625</i>	<i>1,483</i>	<i>1,130</i>	<i>1,130</i>	<i>1,483</i>	<i>954</i>	812	671	1,589	918	2,402	1,307
March.....	<i>1,045</i>	<i>600</i>	<i>988</i>	<i>1,236</i>	<i>954</i>	<i>1,095</i>	<i>636</i>	<i>494</i>	<i>1,024</i>	<i>954</i>	530	459	1,024	706	1,695	826
April.....	<i>1,059</i>	<i>530</i>	<i>2,048</i>	<i>2,931</i>	<i>742</i>	<i>1,130</i>	<i>1,342</i>	<i>1,836</i>	<i>1,836</i>	<i>1,059</i>	565	459	1,942	706	2,861	1,395
May.....	<i>4,273</i>	<i>3,461</i>	<i>5,509</i>	<i>3,037</i>	<i>1,377</i>	<i>3,461</i>	<i>4,450</i>	<i>3,284</i>	<i>2,472</i>	<i>1,907</i>	1,342	1,766	2,896	1,519	.....	2,904
June.....	<i>5,383</i>	<i>2,366</i>	<i>3,496</i>	<i>3,214</i>	<i>2,225</i>	<i>3,178</i>	<i>4,132</i>	<i>2,366</i>	<i>2,861</i>	<i>2,472</i>	1,942	2,048	2,896	2,154	.....	2,906
July.....	<i>5,403</i>	<i>3,779</i>	<i>7,416</i>	<i>3,567</i>	<i>4,450</i>	<i>3,073</i>	<i>3,779</i>	<i>4,238</i>	<i>2,825</i>	<i>3,355</i>	2,190	3,002	3,320	3,320	.....	3,809
August.....	<i>5,816</i>	<i>2,790</i>	<i>6,075</i>	<i>4,732</i>	<i>3,885</i>	<i>4,061</i>	<i>2,931</i>	<i>4,097</i>	<i>4,132</i>	<i>4,238</i>	3,567	2,861	2,790	4,344	.....	3,971
September.....	<i>6,186</i>	<i>3,037</i>	<i>4,379</i>	<i>3,885</i>	<i>4,450</i>	<i>3,390</i>	<i>2,719</i>	<i>3,850</i>	<i>2,543</i>	<i>3,178</i>	3,073	3,638	2,931	4,697	.....	3,756
October.....	<i>6,498</i>	<i>4,450</i>	<i>5,933</i>	<i>3,744</i>	<i>4,697</i>	<i>4,944</i>	<i>2,684</i>	<i>3,850</i>	<i>3,461</i>	<i>3,390</i>	4,520	3,702	4,415	3,956	.....	4,303
November.....	<i>3,956</i>	<i>7,487</i>	<i>7,240</i>	<i>4,556</i>	<i>6,534</i>	<i>3,532</i>	<i>3,249</i>	<i>4,450</i>	<i>5,192</i>	<i>3,744</i>	4,061	6,746	4,732	5,721	.....	5,086
December.....	<i>5,898</i>	<i>5,121</i>	<i>6,075</i>	<i>8,052</i>	<i>10,630</i>	<i>3,779</i>	<i>5,121</i>	<i>4,626</i>	<i>2,296</i>	<i>2,649</i>	2,684	3,143	2,190	7,028	.....	4,949
Year.....	4,172	3,052	4,314	3,605	3,773	3,055	2,750	2,864	2,987	2,572	2,345	2,391	2,969	3,058	.....	3,164
Three dry.....	1,149	695	1,377	2,060	1,107	1,236	1,036	765	1,448	989	636	530	1,518	777	2,319	1,176
Rainy.....	5,180	3,838	5,294	4,120	4,662	3,661	3,317	3,563	3,500	3,100	2,915	3,013	3,453	3,818	.....	3,827

AT BOHIO.

January.....	4,132	2,684	<i>2,331</i>	<i>3,532</i>	7,063	4,556	4,732	2,048	5,651	3,850	2,119	1,483	11,231	1,625	4,944	4,132
February.....	<i>1,554</i>	<i>1,377</i>	<i>1,271</i>	<i>2,331</i>	<i>1,801</i>	<i>1,377</i>	<i>1,554</i>	<i>1,589</i>	<i>1,695</i>	<i>1,731</i>	1,059	989	2,084	1,024	2,331	1,585
March.....	<i>1,271</i>	<i>600</i>	<i>1,165</i>	<i>1,448</i>	<i>1,095</i>	<i>1,059</i>	<i>1,695</i>	<i>706</i>	<i>1,095</i>	<i>989</i>	742	706	1,271	636	1,413	1,009
April.....	<i>1,236</i>	<i>600</i>	<i>2,366</i>	<i>3,426</i>	<i>777</i>	<i>1,059</i>	<i>1,695</i>	<i>883</i>	<i>2,013</i>	<i>1,095</i>	706	565	2,154	565	3,638	1,519
May.....	<i>6,569</i>	<i>5,333</i>	<i>8,476</i>	<i>4,662</i>	<i>3,355</i>	<i>4,167</i>	<i>4,944</i>	<i>7,982</i>	<i>2,684</i>	<i>2,048</i>	1,625	2,296	4,273	1,519	.....	4,281
June.....	<i>8,193</i>	<i>3,214</i>	<i>5,439</i>	<i>4,944</i>	<i>4,273</i>	<i>4,309</i>	<i>4,203</i>	<i>4,203</i>	<i>3,355</i>	<i>3,143</i>	2,861	2,790	3,178	2,543	.....	4,046
July.....	<i>8,300</i>	<i>4,803</i>	<i>11,407</i>	<i>7,628</i>	<i>6,216</i>	<i>4,591</i>	<i>3,143</i>	<i>5,121</i>	<i>6,509</i>	<i>3,956</i>	5,615	3,178	3,037	4,026	.....	5,542
August.....	<i>8,759</i>	<i>4,521</i>	<i>9,359</i>	<i>10,772</i>	<i>6,498</i>	<i>6,922</i>	<i>3,496</i>	<i>7,275</i>	<i>5,298</i>	<i>5,721</i>	5,262	4,309	3,390	5,474	.....	6,218
September.....	<i>10,489</i>	<i>4,344</i>	<i>6,746</i>	<i>7,664</i>	<i>7,452</i>	<i>5,792</i>	<i>5,933</i>	<i>6,887</i>	<i>3,214</i>	<i>4,238</i>	4,768	5,792	3,920	5,686	.....	5,923
October.....	<i>9,995</i>	<i>6,851</i>	<i>9,112</i>	<i>8,582</i>	<i>9,359</i>	<i>6,922</i>	<i>6,357</i>	<i>7,487</i>	<i>5,050</i>	<i>4,944</i>	6,993	6,322	5,933	5,580	.....	7,106
November.....	<i>6,075</i>	<i>11,513</i>	<i>14,125</i>	<i>11,443</i>	<i>12,714</i>	<i>6,075</i>	<i>7,593</i>	<i>6,957</i>	<i>7,840</i>	<i>5,296</i>	6,605	13,244	6,675	8,335	.....	8,678
December.....	<i>9,076</i>	<i>7,876</i>	<i>9,359</i>	<i>18,541</i>	<i>12,573</i>	<i>6,957</i>	<i>6,039</i>	<i>6,816</i>	<i>2,861</i>	<i>3,602</i>	3,744	4,591	3,002	10,489	.....	7,538
Year.....	6,304	4,476	6,513	7,081	6,098	4,482	4,216	4,830	3,944	3,384	3,509	3,855	4,179	3,958	.....	4,798
Three dry.....	1,354	859	1,601	2,402	1,224	1,165	1,377	1,059	1,601	1,272	836	753	1,836	742	2,461	1,371
Rainy.....	7,954	5,682	8,150	8,641	7,723	5,588	5,160	6,086	4,725	4,089	4,400	4,889	4,960	5,031	.....	5,940

It is believed that this table presents a trustworthy estimate of the volume delivered by the Chagres during this long period; but it should be remembered that evidence has been offered above tending to show that the river recently has been passing through a period of minimum flow, and that the annual volume would probably be increased if it had been possible to include all the years since work on the canal began.

THE FLOODS OF THE CHAGRES.

Only five great floods have occurred since the canal operations were inaugurated, and the records of the Panama Railroad show that no damages to the road occurred prior to the first of these floods, in 1879. These records cover half a century. The exceptional character of these occurrences and the little probability of their frequent interference with canal traffic are therefore demonstrated. When floods do occur, however, they are sufficiently formidable to demand well-considered measures of regulation, and accordingly all the existing records have received elaborate study.

It is to Gamboa that attention is chiefly attracted, not only because the river first attains the canal at that point, but also because more data have been collected there than at any other single point. The bihourly discharges there are shown in Fig. VII. The different floods will be treated in turn, beginning with the last and following back in order of date.

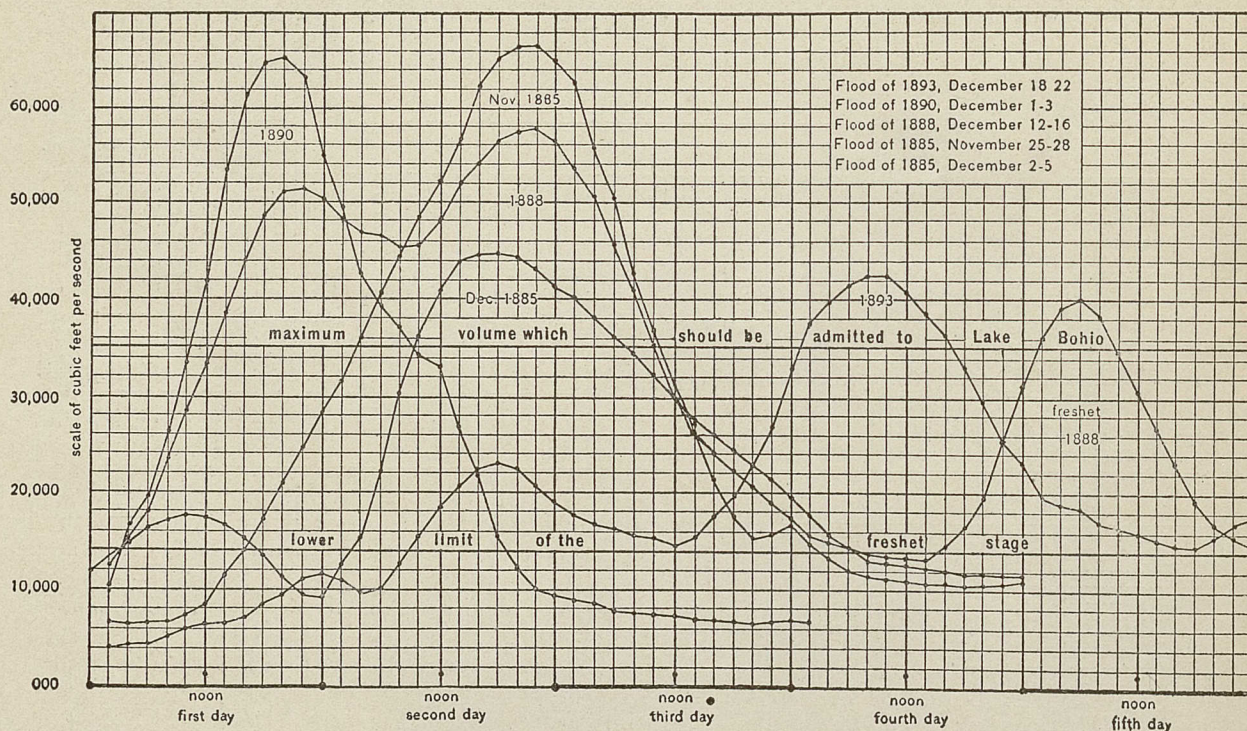


FIG. VII.—Bihourly discharges of the Chagres in its great floods.

Flood of 1893.—This flood was carefully measured, and although it was the least formidable of any it merits special attention. After moderate showers on the 14th, 15th, and 16th of December, a heavy rainfall began on the evening of the 17th and continued until the 24th. During these seven days 13.9 inches of rain fell at Gamboa, and 13.2 inches at Panama. The daily record at Colon was 1.02, 3.35, 4.64, 4.36, 3.47, 2.44, and 1.06 inches, making a total of 20.34 inches. The wind, shifting from south to west and northwest, blew in squalls and heavy gusts, forcing the storm clouds over the entire Isthmus. The inundation caused but little damage. The current attained a velocity of from 8 to 10 feet per second, and brought down a few drift logs and deposited some fine sand a short distance above Buena Vista.

The curve marked "1893" on Fig. VII exhibits the discharges deduced from the bihourly water levels and rating table at Gamboa during this flood. Fifteen actual measurements were made, and the following figures are added to illustrate how accurately the estimate by rating table and fluvograph represents the river. The discrepancy is only about 3 per cent, and that on the safe side.

Date.	Hour.	Height above sea.	Discharge in feet-seconds.			Remarks.
			Meas- ured.	Tabular.	Differ- ence.	
1903.		<i>Meters.</i>				
December 19.....	8.15 a. m.....	17.32	12,714	13,173	— 459	
Do.....	9.00 a. m.....	17.52	13,420	14,223	— 803	
Do.....	10.30 a. m.....	17.94	14,833	16,669	—1,836	
Do.....	4.40 p. m.....	18.94	23,380	22,850	+ 530	
December 20.....	8.45 a. m.....	17.79	15,857	15,751	+ 106	
December 21.....	9.50 a. m.....	21.52	35,757	35,939	— 182	
Do.....	4.30 p. m.....	20.52	28,465	33,904	—5,439	River falling rapidly.
December 22.....	11.00 a. m.....	17.86	16,387	16,175	+ 212	
Do.....	3.20 p. m.....	17.63	14,409	14,868	— 459	
December 23.....	7.35 a. m.....	17.05	11,619	11,760	— 141	
Do.....	3.50 p. m.....	17.22	12,679	12,643	+ 36	
December 24.....	10.40 a. m.....	16.67	9,853	9,853	000	
Do.....	3.10 p. m.....	16.31	7,805	8,193	— 388	
December 25.....	8.10 a. m.....	15.89	7,452	6,392	+1,060	
Do.....	2.45 p. m.....	15.81	7,063	6,075	+ 988	
Mean.....			15,446	15,899	— 453	

It is shown by Fig. VII that the flood presented itself in three waves, of which the first and last were ordinary freshets, but that the intermediate rise attained at Gamboa at 9 a. m. on December 21 a level of 25.33 feet above low water, with a maximum volume of 43,086 cubic feet per second. The largest discharge in forty-eight hours occurred between 10 p. m. of December 20 and 10 p. m. of December 22, being 27,971 cubic feet per second, or 65 per cent of the maximum. This percentage has an important bearing upon the problem of regulation, as will appear later.

The river in floods receives considerable contributions from the tributaries intermediate between Gamboa and Bohio, 20 miles below. Moreover, the lowlands of Tavernilla, between Bohio and San Pablo, are always inundated at such times, and this exerts an important regulating effect on the wave which reaches Bohio, reducing its height and prolonging its flow. These modifying influences in the flood of 1893 nearly masked the three waves and united them in one. The highest level attained at Bohio was reached at midnight on December 21, being 28.54 feet above low water, with a maximum discharge of 51,100 cubic feet per second. The largest volume in forty-eight hours passed at the same time as at Gamboa, and was 43,590 cubic feet per second, or 85 per cent of the maximum. To avoid confusion, the curves at Bohio are not shown on Fig. VII.

Flood of 1890.—This flood was of a quite different type from that of 1893. The river at Gamboa rose with unexampled rapidity about 25 feet in seventeen hours, and immediately subsided about 21 feet in twenty-three hours. These figures at Bohio were 19 feet in thirty-one hours and 11 feet in fourteen hours. This is the most sudden and violent oscillation of the Chagres of which there are records, and it places in a strong light the exaggerations which have been current. The Senate Committee on Inter-oceanic Canals was informed under oath in February, 1902, that a rise "as high as 52 feet in two hours" was reported.

This flood was naturally more destructive than that of 1893. In the morning of December 1 the river began to rise rapidly, carrying huge drift logs and waifs of every description. At 9 p. m. it reached the flooring and swept away part of the bridge near Gorgona, wrecked a dredge, and did other damage. Railroad communication had already been interrupted between Matachin and Gorgona by 5 feet of water on the rails; it soon stood about 1.5 feet deep on the line between Bohio and Barbacoas and between Lion Hill and Gatun; and by 2 a. m. of December 2 it had invaded the line between Frijoles and Tavernilla. Traffic was restored on December 3 by the rapid fall of the river.

The highest level was reached at Gamboa at 8 p. m. on December 1, being 31.82 feet above low water; at Bohio it was reached at 1 p. m. of December 2 and remained unchanged for three hours, being 32.15 above low water. The corresponding discharges were 65,371 and 71,660 cubic feet per second. The largest average discharge in forty-eight hours at Gamboa occurred between 2 a. m. of December 1 and 2 a. m. of December 3, and was 34,752 cubic feet per second, or 54 per cent of the maximum; at Bohio it occurred between noon of December 1 and noon of December 3, and was 51,068 cubic feet per second, or 71 per cent of the maximum. Bihourly details are shown on Figure VII.

Only one actual gauging was made at Gamboa during this flood, at about 4 p. m. on December 2, indicating a discharge of 14,303 cubic feet per second, the river being 13 feet above low water. By fluviograph and rating table the volume was 19,636 cubic feet, the difference being explained by the fact that the river was falling rapidly. At Bohio two gaugings were made, at 7 a. m. and at 1 p. m. December 2, the river being 30.8 feet and 32.15 feet above low water. The corresponding discharges were 64,877 and 75,048 cubic feet per second. The volumes by the fluviograph and rating table were 65,512 and 71,657 cubic feet.

Flood of 1888.—This flood, although it attained a less height by about 6 inches than that of 1890, was more formidable by reason of its long duration. The rise at Gamboa began on December 11 from a level only about 2 feet above low water, mounted rapidly about 22 feet, subsided slightly only to resume its upward movement, attained its highest point 31.37 feet above low water at 9 p. m. on December 13, subsided gradually for about forty-eight hours, and then after developing into a large freshet finally fell on December 17 below the 10-foot stage, which marks the lower limit of ordinary rises. It had remained above this stage for one hundred and twenty-eight hours. There were other freshets of moderate height but of unusual duration in this month, giving a record of four hundred and twenty-four hours above the 10-foot stage, or more than double that of any other month in the twenty years of which we have records. December, 1888, would doubtless have tested any system of river regulation more severely than any other in the last half century except November, 1879. Unfortunately no fluvigraph record is available at Bohio. The extreme height there was about 34.68 feet above low water, indicating a discharge of 79,000 cubic feet per second.

At Gamboa the maximum discharge was 58,132 cubic feet per second; the largest in forty-eight hours, occurring between noon of the 12th and noon of the 14th, was 48,278 cubic feet, or 83 per cent of the maximum, the largest percentage noted. Bihourly details of the flood will be found on Figure VII, including those of the freshet which followed so closely on December 15–16 as to be not without importance in connection with the problem of regulation.

It may be remarked here that the distinction between the so-called freshets of the Chagres and its great floods is based not only on the extreme height attained, but also on the duration. The floods result from heavy rainfalls in the basin, lasting for several days, while freshets follow much shorter downpours. In the latter the high stage of the river seldom continues for more than twenty-four hours, and the average discharge in that period has been adopted as the standard for comparing them. This freshet of December 15–16 was one of the largest of them, giving the average discharge at Gamboa of 28,289 cubic feet per second for twenty-four hours. That of May 16–17, 1897, gave 30,549 cubic feet; that of November 27–28, 1901, gave 25,357 cubic feet. They are liable to occur in any month except February and March. Two of them occurred even in January, in 1902, giving discharges for twenty-four hours of 22,532 and 16,811 cubic feet per second. Such volumes, as will appear further on, are considered too large to be permitted to enter a route traversed by ocean steamers.

The inundation caused by the flood of 1888 was extensive. Communication by rail was interrupted for twenty-four hours or more between Matachin and Gorgona, between Frijoles and Tavernilla, between Bohio and Barbacoas, and between Lion Hill and Gatun. A dredge was swept away and one of the crew was drowned. Injuries were done to the canal between 16 and 22 kilometers from Colon, and other damages were reported.

Flood of 1885.—This flood also presented peculiar features. The rise at Gamboa began on November 25 from a level about 6.5 feet above low water, mounted steadily for thirty-six hours to the maximum height, 31.50 feet above low water, then "after a few moments" subsided rapidly nearly to the 10-foot level, there oscillated for five days, and finally on December 3–5 developed into a second flood smaller than the first, but quite comparable at Gamboa with that of 1893. This was the first flood to occur after work had begun on the canal, and some attempts at measuring the discharge were made, but a diligent search among the old documents has failed to discover details as to methods of gauging or of reduction. An approximate rating table was found which at some levels compares well with later studies. The fluvigraph register has enabled the flood at Gamboa to be analyzed with precision, but unfortunately no records at Bohio are available.

The highest point was reached at Gamboa at 8 p. m. on November 26, with a discharge of 64,488 cubic feet per second. The greatest average for forty-eight hours, between 8 p. m. of November 25 and 8 p. m. of November 27, was 43,404 cubic feet, giving a ratio of 67 per cent of the maximum. The second flood reached its highest level, 24.11 feet above low water, at from 4 to 6 p. m. on December 3, with a discharge of 44,923 cubic feet per second. The greatest average for forty-eight hours, between 5 a. m. of December 3 and 5 a. m. of December 5, was 32,421 cubic feet per second, giving a ratio of 72 per cent. The greatest heights attained at Bohio in these two rises were approximately 33.79 feet and 26.41 feet above low water, indicating discharges of 74,800 and 47,466 cubic feet per second.

Flood of 1879.—Abundant evidence exists to establish that this flood considerably exceeded any one of later date, and hence that any safe plan of regulation must take it into account. It occurred in November, when a violent rain storm with strong northerly winds prevailed for six days over the entire Isthmus. The only rain record was kept at Panama, where 12.6 inches fell; but this fact warrants no conclusion as to what fell in the valley of the Chagres, where precipitation is always much larger and is often double the volume at Panama. The river data are also meager. The water level at Gatun attained a height of 23 feet above mean tide, exceeded at Bohio 39 feet, and at Barbacoas reached 62.3 feet. These facts were officially reported on April 29, 1884, by

M. Clavenad, chief engineer of the first and second divisions, which included this district. An investigation of water levels was confided, shortly after the occurrence of the flood of 1888, to M. Sosa, a Colombian engineer of high repute who had been educated in the United States, and who subsequently became a member of the comité technique. He assured me personally that the evidence collected left no doubt that the volume carried in 1879 must have been much larger than in any later flood. The following figures exhibit his determinations of relative level in what are unquestionably the two greatest known floods of the river, they give the height, in feet above mean tide, of the highest water levels:

	Flood of 1879.	Flood of 1888.	Difference.
At Buena Vista	43.96	39.96	4.00
At Bohío	39.37	34.68	4.69
Difference	4.59	5.28	.69

Another examination made shortly after the flood of 1888 near San Pablo, where the railroad bridge at Barbacoas afforded a trustworthy point of reference, went to prove that there, too, the flood of 1879 reach a point "higher than in 1888, but not very much higher."

It has been suggested, in the desire to reduce the cost of the regulating works, that the extensive excavations made by the old canal company between 1879 and 1888 may have lowered the water level in the latter flood, and thus have suggested an exaggerated idea as to the relative volume carried in the former. The facts do not warrant this claim. The excavations near and above Bohío did not sensibly increase the direct channel way in that region, being oblique to and at a considerable distance from the direct route of flow. Near the site of the dam the natural channel of the river is contracted and sweeps round a sharp bend of more than 90 degrees, creating an obstruction that in floods must oppose much resistance and be the dominating obstacle to the flow. This obstacle was the same in both floods. Below Bohío considerable excavations had been made, and if they had tended to lower the water level their effect should have been much more apparent at Bohío, below the gorge, than at Buena Vista, a mile and a half above. But the records just quoted indicate that the fall in water surface between Buena Vista and Bohío in the two floods was so nearly identical as to render the large difference in absolute level between them inexplicable upon any other supposition than that of a much larger volume passing in 1879 than in 1888. Moreover, as a matter of fact, in both floods the whole region below Bohío was deeply inundated, and in so enormous a waterway an increase of 2,500 square feet, largely estimated, could not have materially lowered the general level. On the contrary, the cuttings across the natural bends in the lower river may have caused in 1888 whirls and cross currents tending even to raise it. It is clear that the only conservative estimate to be formed of the maximum momentary discharge at Bohío in the flood of 1879, is that to be derived from the recorded water level 39.37 feet above zero; and this by the rating table is shown to be 112,730 cubic feet per second.

Unfortunately no water levels in this flood were secured at Gamboa, but the fact that the oscillations in this lower part of the basin are quite similar justifies the following computation, based on the comparative levels attained in the other four floods. The table gives the extreme heights above mean sea level in meters, and the figures below indicate the calculations to deduce the probable height at Gamboa. The probable levels at Bohío in the flood of 1885 are deduced in a similar manner.

Locality.	1879.	Novem- ber, 1885.	Decem- ber, 1885.	1888.	1890.	1893.
Gamboa	25.17?	23.60	21.35	23.56	23.70	21.72
Buena Vista	13.40			12.18		
Bohío	12.00	10.30?	8.05?	10.57	9.80	8.70

$$23.56 + (12.00 - 10.57) = 24.99$$

$$23.56 + (13.40 - 12.18) = 24.78$$

$$23.70 + (12.00 - 9.80) = 25.90$$

$$21.72 + (12.00 - 8.70) = 25.02$$

$$\text{Resulting height} \dots\dots 25.17 \pm 0.17 \text{ meter.}$$

In other words, the extreme height of the flood of 1879 at Gamboa was 36.65 feet above low water, with a probable error of about 6 inches. This would indicate a maximum momentary discharge of 78,614 cubic feet per second.

THE FRESHET PROBLEM.

But the great floods are by means the only elements to be considered in forming plans for regulating so variable a stream. During the dry months the flow of the Chagres is gentle and nearly uniform, but during the rainy months freshets are always to be expected. They are caused by local downpours of rain which often last two or three days. The resulting rises of the stream are short lived but violent, as may be seen from the example, by no means extreme, shown in Table 6.

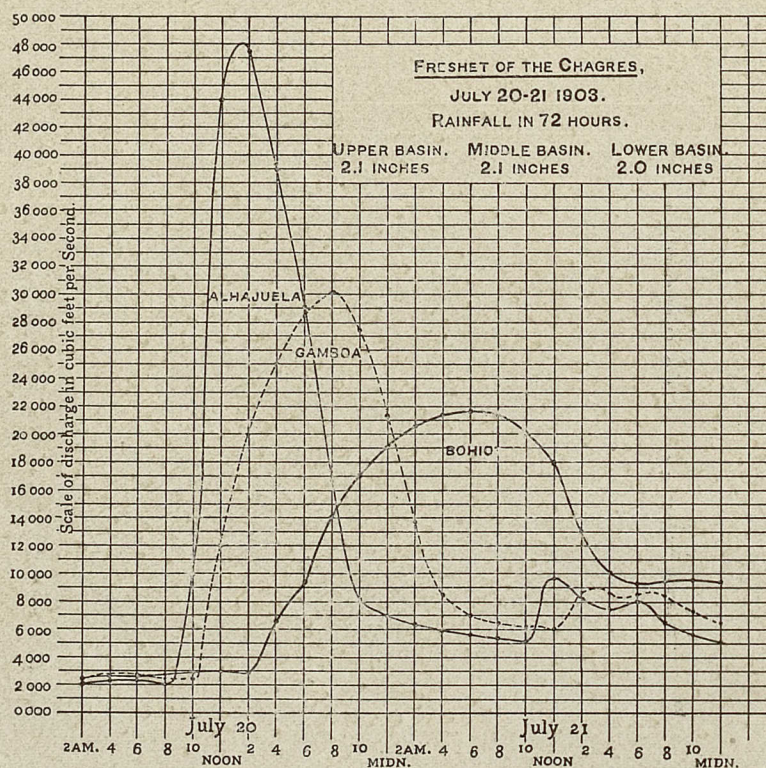


FIG. VIII.—Typical freshet of the Chagres.

TABLE 6.—Freshet of July 20-21, 1903.

Hour.		Height above sea, in meters.		Discharge, in cubic feet per second.	
		July 20.	July 21.	July 20.	July 21.
ALHAJUELA.					
2 a. m.	.....	28.64	29.20	2,119	6,357
4 a. m.	.....	28.66	29.14	2,225	5,933
6 a. m.	.....	28.66	29.10	2,225	5,651
8 a. m.	.....	28.63	29.07	2,084	5,439
10 a. m.	.....	29.70	29.03	10,136	5,191
Noon.	.....	32.80	29.66	43,934	9,810
2 p. m.	.....	33.15	29.45	48,560	8,193
4 p. m.	.....	32.40	29.37	38,778	7,593
6 p. m.	.....	31.60	29.42	29,066	7,946
8 p. m.	.....	30.40	29.17	16,352	6,145
10 p. m.	.....	29.45	29.10	8,193	5,651
Midnight.	.....	29.28	29.01	6,922	5,050
GAMBOA.					
2 a. m.	.....	14.80	17.00	2,613	13,844
4 a. m.	.....	14.90	16.00	2,931	8,617
6 a. m.	.....	14.88	15.64	2,861	6,957
8 a. m.	.....	14.80	15.54	2,613	6,534
10 a. m.	.....	14.78	15.48	2,543	6,286
Noon.	.....	17.10	15.42	12,009	6,004
2 p. m.	.....	18.00	16.00	19,919	8,617
4 p. m.	.....	18.76	16.00	25,004	8,617
6 p. m.	.....	19.28	15.90	28,712	8,158
8 p. m.	.....	19.48	15.90	30,160	8,158
10 p. m.	.....	19.08	15.70	27,264	7,240
Midnight.	.....	18.20	15.56	21,225	6,604

TABLE 6.—*Freshet of July 20-21, 1903—Continued.*

BOHIO.

Hour.	Height above sea, in meters.		Discharge, in cubic feet per second.	
	July 20.	July 21.	July 20.	July 21.
2 a. m.	1.31	5.10	2,543	20,448
4 a. m.	1.32	5.20	2,578	21,119
6 a. m.	1.35	5.28	2,649	21,684
8 a. m.	1.42	5.27	2,790	21,614
10 a. m.	1.47	5.05	2,931	20,130
Noon	1.47	4.70	2,931	17,885
2 p. m.	1.42	3.80	2,790	12,820
4 p. m.	2.40	3.20	6,746	9,959
6 p. m.	3.40	3.00	9,078	9,112
8 p. m.	4.06	3.06	14,162	9,359
10 p. m.	4.55	3.10	16,952	9,536
Midnight	4.89	3.08	19,071	9,465

Fig. VIII is added to present it more clearly to the eye. The frequency of these freshets and the rate of movement of their crests have been considered above; here it only remains to record their volumes.

To form an intelligent idea of the provisions to be adopted for controlling the flow of such a stream it is needful to study the volumes that, without regulation by a lake above, may be expected to strike the canal route near Gamboa, carrying more or less matter in suspension and rolling sand and gravel on the bottom, and to traverse the artificial lake extending from that point to Bohio. Table 7 has been prepared to give this information. High rises of the Chagres rarely continue more than about twenty-four hours, and that period has been adopted as the standard of duration, selecting the hours so as to show the maximum daily flow. The list has been chosen from a wealth of examples to illustrate three characteristic types, determined by the locality in the basin which received the larger part of the rainfall.

Table 7 gives both the average and the maximum volume at each locality, as well as the rainfall in each subbasin to which it was due, as nearly as this latter can be estimated from the daily records. In comparing different freshets and corresponding rainfall it must not be forgotten that the average volume is largely dependent upon the stage of the stream when it received the addition, and hence that maximum volumes furnish a better criterion. The average volumes are added to afford data for estimating the total contributions during the twenty-four hours, under the actual conditions then existing.

TABLE 7.—*Typical freshets and floods, classed by locus of rainfall.*

RAINFALL CHIEFLY IN UPPER BASIN.

Date.	Rainfall in subbasin, in inches, in 72 hours.			Discharge, in cubic feet per second, for 24 hours.					
	Upper.	Middle.	Lower.	Alhajuela.		Gamboa.		Bohio.	
				Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
May, 1899	6.0	0.3	1.8	10,348	30,725	9,641	20,484	10,807	17,588
August, 1900	3.9	1.7	1.3	10,383	22,850	10,736	20,625	14,374	18,612
August, 1903	4.7	3.2	1.5	11,760	30,831	17,270	25,922	21,402	27,547
November, 1903	3.4	1.3	1.9	24,631	44,252	24,192	35,348	30,831	36,305
Means	4.5	1.6	1.6	14,268	32,173	15,469	25,675	19,354	25,004

RAINFALL CHIEFLY IN LOWER BASIN.

December, 1900	1.1	0.8	2.6	14,762	23,486	14,974	21,932	18,259	22,885
January, 1902	1.2	4.1	7.7	10,389	23,945	22,532	26,629	37,153	38,107
December, 1903	1.6	3.0	3.4	5,898	6,922	9,641	14,339	20,307	22,391
Means	1.3	2.6	4.6	13,350	18,117	15,716	20,978	25,251	27,974

TABLE 7.—*Typical freshets and floods, classed by locus of rainfall—Continued.*

RAINFALL WELL DISTRIBUTED.

Date.	Rainfall in subbasin, in inches, in 72 hours.			Discharge, in cubic feet per second, for 24 hours.					
	Upper.	Middle.	Lower.	Alhajuela.		Gamboa.		Bohio.	
				Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
August, 1899	1.5	1.3	1.1	15,080	29,771	16,634	26,205	19,919	25,887
November, 1899	2.5	3.9	3.1	11,160	30,937	12,855	23,132	18,859	24,333
October, 1900	3.0	3.6	1.9	11,549	26,805	14,621	23,521	16,528	20,837
November, 1901	6.0	4.5	6.1	11,301	19,071	16,917	25,075	28,995	33,233
Do	2.6	1.8	2.1	13,738	22,497	15,116	21,296	24,474	26,699
Do	4.8	2.9	4.6	21,119	43,581	25,357	36,871	33,727	40,508
August, 1902	1.3	1.6	2.3	11,725	30,231	14,415	23,803	14,586	19,777
October, 1902	2.4	2.0	2.2	11,725	26,805	15,998	26,629	18,683	24,262
July, 1903	2.1	2.1	2.0	18,788	49,231	17,411	30,160	17,305	21,684
December, 1903	3.5	3.0	3.2	14,550	19,989	11,725	14,339	17,870	19,623
Do	2.8	3.0	3.0	9,747	16,917	12,679	19,354	19,777	21,826
January, 1904	2.0	1.3	1.5	11,902	22,179	13,102	22,461	13,809	16,881
Means	2.9	2.6	2.8	13,526	28,147	15,575	24,545	20,378	24,616

TWO OLDER FRESHETS AND THE SIX FLOODS.

December, 1888 .....	.....	.....	.....	.....	.....	30,867	40,014	.....	.....
May, 1897 .....	.....	.....	.....	.....	.....	30,549	42,380	.....	.....
November, 1879 .....	.....	.....	.....	.....	.....	.....	78,615	.....	112,731
November, 1885 .....	.....	.....	.....	.....	.....	57,001	64,488	.....	74,801
December, 1885 .....	.....	.....	.....	.....	.....	40,755	44,923	.....	47,501
December, 1888 .....	.....	.....	.....	.....	.....	51,809	58,202	.....	79,004
December, 1890 .....	.....	.....	.....	.....	.....	50,185	65,371	64,347	71,657
December, 1893 .....	.....	.....	.....	.....	.....	39,449	43,157	48,490	51,068

Some interesting facts as to stream flow in this region may be gleaned from this table. Thus in freshets resulting from a rainfall well distributed over the basin, the larger maximum flow occurs at upper stations, and this usual river rule is naturally more pronounced when there is a larger relative downfall in the mountain district; in the opposite case the rule is reversed. Nevertheless, although unfortunately no great flood data have ever been collected at Alhajuela, it is apparent from the measurements below that at such times when widespread and long continued downpours prevail, and the entire region is surcharged with water, the rule is reversed. In every recorded instance the discharge at the height of the flood was greater at Bohio than at Gamboa. This fact is probably in part due to peculiar conditions governing the local slope at such times. At the lowest stage the level of the ocean is here nearly attained, and as the water rises the local slope rapidly increases, and is sustained by flow from a large district just above which is then always inundated. Above, near Gamboa, there is a considerable natural slope to the bed, and this furnishes reserves as the water rises, limiting the height attained and hence the maximum volume. The extreme oscillation at Bohio is greater than at any other known point of the valley.

PLANS FOR CONTROLLING THE FLOW.

Such plans must take into account both the floods and the freshets, and must protect the entire district traversed jointly by the Chagres and the canal from Gamboa to the Atlantic coast.

Volume to hold back at Bohio.—This problem resolves itself into determining what part of the great floods should be held back temporarily, and where the reservoir lake or lakes should be located, when resort is had to the familiar method of slack-water navigation. The summary of results already reached given in Table 8 will be found convenient for reference. It will be remembered that low water at Bohio is taken as 0 meters, and at Gamboa as 14 meters above mean sea level.

TABLE 8.—*Summary of great floods.*

Floods.	At Gamboa.				At Bohio.			
	Maximum height above low water.	Discharge.			Maximum height above low water.	Discharge.		
		Maximum.	In 48 hours.	Per cent.		Maximum.	In 48 hours.	Per cent.
	<i>Feet.</i>	<i>Foot-secs.</i>	<i>Foot-secs.</i>	<i>Foot-secs.</i>	<i>Feet.</i>	<i>Foot-secs.</i>	<i>Foot-secs.</i>	<i>Foot-secs.</i>
1893	25.33	43,086	27,971	65	28.54	51,100	43,590	85
1890	31.82	65,371	34,752	54	32.15	71,660	51,068	71
1888	31.37	58,132	48,278	83	34.68	79,000	(?)	(?)
November, 1885	31.50	64,488	43,404	67	33.79	74,800	(?)	(?)
December, 1885	24.11	44,923	32,421	72	26.41	47,466	(?)	(?)
1879	36.65	78,614	(?)	(?)	39.37	112,730	(?)	(?)

The facts known relative to the great floods warrant the belief that at Gamboa the period of danger may safely be estimated at forty-eight hours, and that the percentage of the maximum volume which passed in that period in 1879 may safely be taken at that measured in the similar flood of 1888, which was 83 per cent. These figures give for the total volume to be dealt with at Gamboa, in the greatest of known floods, a discharge of 65,250 cubic feet per second for forty-eight hours, or a total volume of 206,000 acre-feet.

At Bohio the problem is more complex, by reason of considerable contributions from the intermediate tributaries, and of the reserved volumes held back by the flooded areas, which have always tended to reduce the maximum discharge and to prolong the duration of dangerous flow. Moreover, fewer measured percentages are available there than at Gamboa, and those that are known run higher, as is natural. Furthermore, the lowest practicable location for a dam is found at Bohio, and this introduces the question of what volume may safely be allowed to pass to the region below in these great floods. For these reasons a different mode of estimating the duration of danger at this point seems to be desirable.

As will appear below, observations of present conditions and of the capacity of the channels to be provided below Bohio, satisfied the comité technique that about 42,000 cubic feet per second could be allowed to leave the artificial lake and pass thence independently to the sea without causing serious overflow or otherwise interfering with the service of the canal. What especially calls for study, therefore, is the duration of the period in which the river at Bohio delivered a volume greater than this in each of the unknown floods, by noting what occurred in the two for which data have been preserved. This estimate may be made upon various suppositions, but the most logical and conservative appears to be that the duration in question was proportional to the relative maximum heights reached in the floods to be compared. This simply assumes that the hourly curve of rise and fall near the dangerous period in the unknown flood was essentially parallel to that observed in the known flood.

Applying this method to the floods of 1893 and 1890, it will be found from the tables of hourly flow that in the former the discharge equaled or exceeded 42,000 cubic feet per second between the hours of 10 a. m. on December 21 and 1 p. m. on December 22, a period of twenty-seven hours, and in the latter, between the hours of 7 p. m. on December 1 and 3 a. m. on December 3, a period of thirty-two hours, the intermediate average discharges being 47,400 and 60,300 cubic feet per second. The extreme heights attained above low water and the corresponding maximum discharges are given in Table 8. It remains to make use of these data for estimating the volumes which passed below Bohio in the four unknown floods by comparing each of them in turn with the two known floods as a standard.

Standard, the flood of 1893 (47,400 foot-seconds for 27 hours).

FLOOD OF 1888.

$$\frac{47,400}{51,100} \times 79,000 = 73,320 \text{ foot-seconds for } \frac{34.7}{28.5} \times 27 = 32.9 \text{ hours.}$$

FLOOD NOVEMBER, 1885.

$$\frac{47,400}{51,100} \times 74,800 = 69,420 \text{ foot-seconds for } \frac{33.8}{28.5} \times 27 = 32.0 \text{ hours.}$$

FLOOD DECEMBER, 1885.

$$\frac{47,400}{51,100} \times 47,466 = 44,100 \text{ foot-seconds for } \frac{26.4}{28.5} \times 27 = 25.0 \text{ hours.}$$

FLOOD OF 1879.

$$\frac{47,400}{51,100} \times 112,730 = 104,600 \text{ foot-seconds for } \frac{39.4}{28.5} \times 27 = 37.3 \text{ hours.}$$

Standard, the flood of 1890 (60,300 foot-seconds for 32 hours).

FLOOD OF 1888.

$$\frac{60,300}{71,660} \times 79,000 = 66,460 \text{ foot-seconds for } \frac{34.7}{32.1} \times 32 = 34.6 \text{ hours.}$$

FLOOD NOVEMBER, 1885.

$$\frac{60,300}{71,660} \times 74,800 = 62,900 \text{ foot-seconds for } \frac{33.8}{32.1} \times 32 = 33.7 \text{ hours.}$$

FLOOD DECEMBER, 1885.

$$\frac{60,300}{71,660} \times 47,466 = 39,940 \text{ foot-seconds for } \frac{26.4}{32.1} \times 32 = 26.3 \text{ hours.}$$

FLOOD OF 1879.

$$\frac{60,300}{71,660} \times 112,730 = 94,800 \text{ foot-seconds for } \frac{39.4}{32.1} \times 32 = 39.3 \text{ hours.}$$

In order to compare these results it is only needful to reduce them to a common unit; for example, the number of acre-feet of water which should be impounded in the reservoir or reservoirs above Bohio in order to protect the canal and region below against inundation. This is done by deducting 42,000 from each of the above discharges, multiplying the remainders by the corresponding hours reduced to seconds, and dividing the product by 43,560 (the number of square feet in an acre). Performing these operations the following values for the needful capacity will be found:

	Acre-feet.
Flood of 1893 (actually measured)	12, 100
Flood of 1890 (actually measured)	48, 400
Flood of 1888 (compared with 1893)	85, 100
Flood of 1888 (compared with 1890)	69, 900
Flood November, 1885 (compared with 1893)	72, 600
Flood November, 1885 (compared with 1890)	58, 200
Flood December, 1885 (compared with 1893)	4, 330
Flood December, 1885 (compared with 1890)	Nothing.
Flood of 1879 (compared with 1893)	193, 200
Flood of 1879 (compared with 1890)	171, 400

These figures confirm what all the known facts and records tend to establish; to wit, that the flood of 1879 so much exceeded any other that it is a safe, and the only safe, standard upon which to base plans for regulation. In adopting definite figures, the indications based on the flood of 1893 should have preference, for although that of 1890 much exceeded it in violence, the exceptional suddenness of its rise and fall and its comparative short duration would make it an unsafe dependence. The flood of December, 1885, has never heretofore been submitted to analysis, and the above figures demonstrate that at Bohio it had no importance; the volume, as will appear further on, proceeded chiefly from the upper Chagres, receiving but small contributions from the tributaries below Gamboa, but at that point it was sufficiently formidable to be worthy of consideration.

The precise reservoir capacity to be provided above Bohio is too important an element to be lightly treated, or to admit of an underestimate without incurring risks of serious calamities. It was the unanimous opinion of the comité technique that the flood of 1879, supplemented as to duration by the data secured in 1893, should form the basis of the *projet*. Furthermore, bearing in mind that the use of the ratio eight-tenths in reducing the gaugings (adopted to avoid any possible overestimate of low-water supply) entails a safety coefficient for flood volumes, it was agreed unanimously to adopt 250,000,000 cubic meters (about 203,000 acre-feet) as the total reservoir capacity demanded above Bohio. Such a reserve will protect the entire valley occupied jointly by the river and canal against overflow, providing a safe system of regulating the volume allowed to escape from Lake Bohio is furnished.

* * * * *

WATER SUPPLY OF THE CANAL.

A precise and well-grounded estimate of the contributions of the river that can be made available to serve the needs of the canal, either directly or by storage in suitable reservoirs, is even more important than a knowledge of the volumes carried in the great floods. Any mistake here might be productive of consequences too serious to be contemplated. The demands of the three dry months, February, March, and April, and that for the entire year need only be considered, as during the remaining nine months the natural flow of the river is ample to meet all possible requirements.

It was to place beyond cavil the estimates of direct flow that the labor represented by Table 23, showing the mean monthly discharge at the three gauging stations for more than fourteen years, was undertaken. It certainly leaves nothing to be desired, since the freshet analysis in Table 21 demonstrates that the river has recently been passing through one of its minimum epochs.

The following conclusions are based on Table 5: The mean trimonthly discharge during February, March, and April is shown to be at Alhajuela 965 cubic feet per second, at Gamboa 1,176 cubic feet, and at Bohio 1,371 cubic feet, the corresponding absolute minima being 530, 530, and 753 cubic feet, the latter occurring in the year 1901. So also in regard to the total annual volume which the river can supply, an important consideration when the annual traffic

shall approach the maximum that can be mechanically accommodated (about 23,000,000 tons), this table furnishes the desired information. The average volume at Alhajuela is 2,424 cubic feet per second; at Gamboa, 3,164 cubic feet, and at Bohio, 4,798 cubic feet, the corresponding minima being 1,837 cubic feet, 2,345 cubic feet, and 3,384 cubic feet, the latter noted at Alhajuela and Gamboa in the year 1900 and at Bohio in 1899. These final estimates do not differ materially from those formed long ago by the engineers of the New Canal Company.

It remains to form an estimate of the volume of water required for the operation of the canal. Two epochs will be considered: First, assuming the traffic which may be anticipated during the early years after the opening, say 10,000,000 tons, requiring the passage daily for three hundred and twenty days annually of 10 convoys moving in one or the other direction, each having an average tonnage of 3,000 tons; second, when the full capacity of the canal as projected is attained, calling for 24 such transits in one or the other direction, and yielding a traffic of about 23,000,000 tons.

Until the dimensions of the locks are finally fixed, which can hardly be considered the case at present, the computations must remain subject to revision; but, as will appear below, moderate changes in these dimensions will affect the total volume of water required in so small a percentage as to be negligible in a general study. For this reason it has appeared better to present the definite figures of the *projet* formulated by the comité technique rather than to introduce uncertain modifications. This *projet* was based on the probable commercial requirements of the canal for the next fifty years, after extensive correspondence with leading shippers and shipbuilders.

The volume of the lockages for a passage through the canal may be estimated from the general formula, applied to each slope, in which N denotes the largest number of locks in flight and V the corresponding largest water prism:

$$(7) \text{ Total lockages on slope} = \frac{N+2}{4} V$$

The other elements of the problem, all of which are independent of the traffic and nearly so of the dimensions of the locks, will be considered in turn. Evaporation at all exposed water surfaces was assumed at 6 millimeters (0.24 inch) per twenty-four hours. Loss by infiltration was allowed the same volume, although, as has been shown above, there is little probability of any important escape. The lighting of the canal, the maneuvers of lock gates, and the aid to shipping in the passage are all to be effected by taking advantage of the artificial fall of about 46 meters (151 feet) at the dam at Alhajuela and at the locks at Bohio. In this manner about 4,300 horsepower will be available, which by the agency of turbines and dynamos may be transferred electrically to the desired points of application with a loss not exceeding 50 per cent, thus furnishing an ample supply for all needs. Table 9 exhibits the continuous water flow per second required.

TABLE 9—*Requisite volume per second.*

Requirements.	Traffic of 10,000,000 tons.		Traffic of 23,000,000 tons.	
	Cubic meters.	Cubic feet.	Cubic meters.	Cubic feet.
For lockages	10	353	24	848
For leakages at gates	3	106	3	106
Evaporation and infiltration	5	177	5	177
False maneuvers	2	71	2	71
Lighting and motive power	7	247	7	247
General contingencies	8	283	8	283
Total	35	1,237	49	1,732

Deducting from these totals the minimum volume which the river itself certainly will contribute during the ninety days of minimum flow, say 700 cubic feet per second at Bohio (500 at Alhajuela), the needful storage capacity to be provided in the lake at Alhajuela can readily be computed. For a traffic of 10,000,000 tons it is 118,000,000 cubic meters, and for 23,000,000 tons 232,000,000 cubic meters.

The site at Alhajuela is exceptionally favorable, * * * The dimensions of the lake furnish a capacity for low-water reserves of 170,000,000 cubic meters, with a further allowance of 150,000,000 cubic meters for flood reserves. To make assurance doubly sure the dam is planned to admit of increased height, either at first or at any future time, permitting increased reserves at the rate of 30,000,000 cubic meters per meter of rise. In fine, the water supply furnished by the Chagres is ample to meet all possible demands, and the provisions for making use of it, projected by the New Company, leave nothing to be desired. Far from being a menace, the river is made a useful friend and ally of the canal.

APPENDIX C.

REPORT OF H. F. DOSE, RESIDENT ENGINEER, COVERING INVESTIGATIONS AT BOHIO,
JUNE 1, 1904, TO FEBRUARY 28, 1905.^a

BOHIO, CANAL ZONE, *March 31, 1905.*

DEAR SIR: In accordance with your instructions of March 4, 1905, I herewith very respectfully submit to you a report pertaining to the investigations, surveys, and examinations at Bohio, and detail cost and distribution of all expenditures incurred under my charge from June 1, 1904, to February 28, 1905, during which time the surveys and investigations relating to the Bohio Dam and other special work assigned to this party were in progress.

Very respectfully,

H. F. DOSE,
Resident Engineer.

Mr. JOHN F. WALLACE,
Chief Engineer Isthmian Canal Commission, Panama.

LOCATIONS EXAMINED, TRACINGS 103 AND 104.

Four possible locations for the dam in the vicinity of Bohio were investigated as follows: First, line C; second, line F; third, line A Z and Buena Vista line.

The first two locations, line C and line F, contemplate closing the valley of the Chagres approximately opposite K 24.2 of the present canal.

Line C, the original French location, crosses the valley in the narrowest place, and runs into the hills on the right side of the Chagres, 3,000 feet above the village of Bohio.

Line F practically starts from the same point near the canal, but makes an angle of $82^{\circ} 32'$ with line C, crosses the valley below the C location and connects with the hills on the opposite side of the valley, 220 feet above the Panama Railroad station, running into the perpendicular bluff of the quarry at Bohio.

Line A Z has the anchorage in common with the C and F locations adjoining the canal, but crosses above the first named and closes the valley of the Chagres and basin of the Rio Aojeta, connecting with the ridge which separates the waters of the Rio Aojeta and Rio Agua Salud immediately above the settlement of Buena Vista.

The Buena Vista line closes the valley of the Chagres immediately above the settlement of that name. This line crosses the present canal location at K 25.6 and connects with the high ground adjoining. On the right side of the valley the latter location has an anchorage in common with line A Z. See tracing 103.

Gigante spillway.—The location of the dam on any of these sites does not reduce the value of the Gigante location for a spillway.

The location of a dam either on lines C, F, or AZ contemplates for the location of locks the excavation between K 23.9 and 24.5 and no change in the present alignment of the canal. A dam on the Buena Vista site necessitates a change of location for the locks and a modification of alignment of the present canal line.

On the lines C and F the rock surface has been developed in detail across the entire valley.

On the line AZ, on account of the unfavorable condition existing there, only one boring was made, and on the Buena Vista location the lowest elevation of rock has been determined with considerable accuracy.

These different projects are taken up in order, and conditions existing there described in detail.

^a The drawings that accompany this report are in the files of the Commission, where they can be examined.

Numbering of borings.—Borings on dam sites are numbered from 200 up, in order not to conflict with previous numbering.

Line C, tracings 89 and 91.—Line C was the site adopted by the Panama Canal Company. It appears to be a very favorable location for a dam. The distance between hundred-foot contours is approximately 1,327 feet. The dam is entirely separated from the lock, which also applies to the F and AZ locations, and a good anchorage exists on each end of the structure.

Numerous borings have been made on the site in the past, but in order to verify the information at hand, and to obtain additional knowledge relating to depth and character of foundations, 21 borings were made and two test pits sunk, all going to rock and extending into the latter several feet, with the exception of hole 210. Nineteen of those holes were approximately on the center line and four on offset lines, three being above and one below the axis of the dam.

Character of material.—In the valley or bottom lands of the Chagres a layer of sandy, yellow clay extends approximately to sea level. This material is free from boulders and uniform in composition, with the exception of a small pocket or vein of sand in hole 201 at elevation +25.

Underlying the yellow clay a blue, sandy clay extends approximately to -50. The latter formation is not so uniform in composition as the former, much vegetable matter being embodied in the material, notably remnants of decayed and, in some instances, very well preserved wood.

Below elevation -50 sand predominates, the material becomes water-bearing and continues so until the bed rock is reached, becoming freely water-bearing as the depth increases. The material gradually changes from sand to very coarse gravel with dimensions which will not pass through a 2-inch ring.

The above classification applies to the greater portion of the section, but a radical difference is noted on the right side of the valley. A layer of clay overlies the rock 20 to 30 feet in thickness from approximately sea level to the lowest portion of the gorge, as indicated on the section herewith submitted (sheet No. 91). This layer is uniform in composition and color, the only foreign substance found therein was a pocket of quicksand at approximately -40 and a deposit of vegetable matter at -135.

On the right side of the gorge a strata of soft rock was also located overlying the hard rock, several feet in thickness. Large boulders were not encountered.

From observations and examinations, it does not appear that the largest bodies of rock embedded in the sand and gravel exceed a cobble stone 6 or 8 inches in diameter.

Well-preserved wood fiber was found at elevation -157.7 in hole 212, and approximately 75 feet below hole 254. This is the lowest elevation where well-preserved wood has been located in this vicinity.

SEEPAGE TESTS, TRACINGS 19, 20, 21, AND 22, SHEETS 7 TO 10.

The material below -50 is water bearing, which becomes more copious as the depth increases. Numerous seepage tests were made in different holes, and in every instance the sand and gravel deposit indicated conclusively that they were water bearing. In every river hole and those holes on shore, where the top of casing was a short distance above the river elevation, a flowing well appeared. This was especially noticeable in holes 209, 243, and 244.

The methods employed in making seepage tests were neither very refined nor complicated. The operation merely consisted in obtaining the elevation of the water in the casing by lowering a float after the drill rods had been removed and obtaining the stage of the Chagres River at the same time. After these elevations had been obtained water was pumped into the pipe until filled and the time required for it to recede to its original level was observed and recorded. Another test was made by lowering the suction end of a force pump into the pipe and drawing the water out of the latter to the end of the suction. The character of the material at the lower end of the casing was also recorded. In case the water remained in the pipe near the top, or lowered very slowly in the first case, or after lowering the level, in the second case, the elevation remained stationary or rose very slowly, the material entered by the casing was pronounced impermeable. If, however, the water ran off very rapidly, or no impression could be made on the elevation by pumping, the material entered was pronounced permeable, or water bearing. During the progress of drilling it was always evident, whether the material was permeable or impermeable. Whenever the flow was entirely lost during drilling—that is, if the water pumped into the casing did not return to the surface, the material penetrated was apparently water bearing. If, however, the return flow was strong, and it appeared that most of the water pumped into the casing during progress of drilling returned, the hole was pronounced tight. (Sheets 7 to 10, tracings 19 to 22, illustrate graphically the conditions in holes 204, 209, 219, and 221.)

From this it seems obvious that the water-bearing strata lying below the clay deposits stand in direct connection with the water of the Chagres. By consulting tracings 15, 89, 91, and 92 this becomes at once apparent.

During normal stages of the river it appears from experiments that the water rises from 1 to 2 feet higher in the casing than the elevation of the river. This is probably due to the fact that the connection between the permeable strata and the bed of the Chagres extends some distance above the location of the section on which that particular boring was made.

During sudden floods it will be seen from sheets 7 to 10 that the plane of the river rises above the plane of the water in the casing, which may be due, perhaps, to the fact that the sand and gravel deposits, acting similar to a filter, do not permit a free and unobstructed passage for the water, and the river recedes before the water has been forced to the elevation to which it would rise if the river remained stationary at flood heights for some time.

From these experiments it appears uncertain whether the water could be sufficiently controlled should it be pertinent to reduce the head for some methods of construction which might be advocated.

Character of rock and core.—On line C the rock was found to be of the same character throughout. It principally consisted of a conglomerate or breccia.

On account of the irregular composition the percentage of core contained from the borings is small, which can be attributed to the nonuniformity of the material penetrated. It is a difficult matter to obtain continuous core in this ground. The harder pebbles and rock deposits in the conglomerate mass grind up the softer or cementing material, which is washed to the surface by the flow, while only the harder formation cores. The latter is subsequently brought to the surface and preserved.

Samples.—Samples of the different strata penetrated were obtained, placed in glass bottles procured for that purpose, properly numbered, labeled, and preserved for future reference.

Three distinctions were made in marking these samples, as follows:

First. Wet or wash samples.

Second. Dry samples.

Third. Core samples.

A wet or wash sample is brought to the surface by the action of the jet from the bottom of the hole and does not accurately represent the character of the material penetrated, the sand, clay, and gravel when combined being separated, the lighter material coming up first.

Dry samples were obtained by forcing hollow pipe into the material, the latter being wedged inside of the cylinder and subsequently brought to the surface. In materials containing some clay excellent results were obtained by this method, but in clear sand or gravel the method was less satisfactory.

Core samples were obtained by drilling into the bed rock either with a diamond drill or a shot machine. The numbers and location of these samples are indicated on the sections submitted, with an explanatory note. (Sheets 91 and 92.)

On lines C 158 earth, including wet and dry samples, and 75.2 feet of core were obtained. All these samples are stored in boxes made for that purpose and plainly labeled.

Total distance.—The total distance between hundred-foot contours on this line is approximately 1,327 feet, distributed as follows:

Below—	+100.	00.	—50.	—100.	—140.	—150.	Feet.
+100	621	191	140	250	50	75	1,327
— 00	191	140	250	50	75	.....	706
— 50	140	250	50	75	.....	.....	515
—100	250	50	75	.....	.....	.....	375
—140	50	75	.....	.....	.....	.....	125
—150	75	.....	.....	.....	.....	.....	75
	1,327	706	515	375	125	75	.....

Greatest depth to rock.—The greatest depth to bed rock suitable for a foundation was found to be at elevation —165 in hole No. 254.

Whether this is the lowest elevation of bed rock in the valley can not be stated with any degree of certainty. It is possible that between adjoining borings depressions may exist which fall below this depth. It is not probable, however, that the lowest elevation could fall sensibly below the maximum depth reported. The rock walls on each side of the valley approach each other with an almost uniform slope. The lowest elevation was found at intersection of lines projected through the general profile of the rock surface, and unless a chasm or fissure is present it is thought the lowest elevation has been reached in hole 254.

LINE F, TRACING 15 AND 92.

This line starts practically from the same location near the canal which serves as anchorage for line C, namely, the isolated rocky hill which separates the dam from the locks near K 24.2 (see tracing 103), but makes an angle of 82° 32', crosses the valley below the C location, and runs

into the perpendicular bluff on the right side of the Chagres River above the railroad station at Bohio.

The profile of bed rock on this line has also been determined with considerable accuracy.

Twenty-nine borings were made and three test pits sunk, all going to rock and extending into the latter several feet with the exception of three holes, 222-227-231, which had to be abandoned on account of accident to the machinery.

Twenty-six of these borings are approximately on the center, and three 60 feet above the axis of the dam.

Line F presents more unfavorable conditions than line C. The distance across the valley is much greater, elevation of bed rock somewhat lower, and the character of foundation less satisfactory than on the C location. On this line the yellow sandy clay extends approximately to sea level, similar to line C, which is followed by blue sandy clay with occasional pockets of yellow sand and deposits of vegetable matter to elevation -110.

Below -110 yellow sand is found, which extends to approximately -120, and below that a strata of coarse gravel, which overlies the bed rock.

The material above the gravel is impervious. No noticeable loss of flow during drilling was experienced, but as soon as the gravel strata was entered the flow was entirely lost.

This description only applies to that portion of the section near the canal where the gravel deposits are comparatively unimportant. As the river is approached the extent of the gravel deposit increases. In hole 253 sand and gravel 110 feet in depth was penetrated. The material also becomes coarser with increased depth. It appears that large boulders are not embedded in the sand and gravel. On several occasions, when the presence of a boulder was suspected, a diamond bit was lowered in order to ascertain the dimensions of the boulder. In no case has the size of the obstruction exceeded 0.5 foot in diameter. In case large isolated rocks or a bed of boulders existed it is probable that with some of the borings they should have been encountered.

All borings, with the exception of three, have been carried to bed rock, and a sample of the latter obtained in every case. The greatest depth of rock suitable for foundation on this line was 201 feet, or 168.3 below datum in hole 221. Considerable difference was found in the character of the rock from conditions existing on line C, and an effort has been made to illustrate graphically on sections C and F accompanying this report the variation in its composition.

Classification bed rock.—To illustrate the variations four classifications were adopted, as follows:

- (a) Very soft rock.
- (b) Soft rock.
- (c) Rock of medium hardness.
- (d) Hard rock.

Under soft rock the decomposed or badly disintegrated rock was placed.

The rock which resembled a compact clay or tufa and can be scratched readily with the finger nail was classified as soft rock.

Rock of medium hardness possesses a degree of hardness similar to sandstone.

Rock harder than sandstone was classified as hard rock.

On line F no regularity was found in the stratification. Layers of hard rock may be followed by volcanic tufa or very soft rock, and in one instance volcanic clay or a very soft tufa was entered after passing through 18 feet of rock of medium hardness.

It is thought that, notwithstanding the irregularity in composition and the apparent unfavorable character of the rock, a suitable foundation could be secured at the depth indicated on the section, but the conditions on line C being so much more favorable it will probably be unnecessary to give this location a serious thought in the future.

Samples.—Samples of both earth and rock were obtained from the borings, labeled and preserved similar to those on line C. A total of 147 earth samples and 206.75 feet of core was secured. These samples are plainly marked and stored away in boxes, which carry an index of their contents. The total distance between 100-foot contours on this line is 2,701 feet, distributed as follows:

Below—	+100	00	-50	-100	-140	-150	Feet.
+100	976	465	280	640	195	145	2,701
00	465	280	640	195	145	.....	1,725
- 50	280	640	195	145	.....	.....	1,260
-100	640	195	145	.....	.....	.....	960
-140	195	145	.....	.....	.....	.....	340
-150	145	.....	.....	.....	.....	.....	145
.....	2,701	1,725	1,260	960	340	145	.....

Greatest depth to foundation.—The lowest elevation of bed rock suitable for foundation was found in hole No. 224 at 168.3 feet below sea level, and it is believed that no elevation greatly in excess of that plane exists. The general profile shows a rolling and irregular line, which can be expected in the geological formation of the territory.

LINE A Z, TRACING 105 AND 107.

The profile of the bed-rock surface has not been developed in detail on account of the apparent unfavorable conditions the location presents. The distance between points of anchorage is much greater, it being approximately 4,000 between the 100-foot contours, and it is probable that the lowest elevation of bed rock suitable for a foundation will not be much higher than on line C.

Nine borings have been made on this line by the Isthmian Canal Commission 1899 to 1901. It was not intended at that time to develop the rock in detail and holes were placed some distance apart. From these investigations it was obvious, however, that depth to bed rock was too great to seriously consider the possibility of constructing a dam on this site with foundations extending to bed rock.

In order to verify previous records and to obtain additional knowledge concerning this location, one boring, hole 208, was made between holes 104 and 105 of the previous Commission, just below the settlement of Buena Vista. Bed rock was located 142.4 below sea level. (See tracing 107.)

With the exception of a blanket of clay extending approximately to sea level, the material overlying the rock was found to be water-bearing sand and gravel. Extensive seepage tests were not made in this hole, but float measurements made at intervals showed that the water in the hole, when water-bearing sand and gravel was entered, fluctuated with the elevation of the Chagres River.

Line A Z starts from a point common to lines C and F near the canal, but crosses the valley above the C location. The upper end of the line connects with the ridge separating the waters of the Rio Aojeta and Rio Agua Salud immediately above the settlement of Buena Vista.

Samples.—Twenty wash samples and 0.7 feet of core were obtained from hole 208 which have been marked and preserved similar to other samples.

The three different projects just described, namely, lines C, F, and A Z have the principal points in common, but in order to maintain the summit level accessory structures will be required.

Gigante spillway, locks, and accessory structures.—The location of a spillway at Gigante, the lock at K.24.2, and permanent structure approximately 700 feet in length to close a temporary river diversion south of the lock apply to each of these projects.

Investigations indicate that these additional structures will securely impound the waters on the F location.

For line C another dam of unimportant dimensions will be required above the village of Bohio. A concrete retaining wall approximately 330 feet in length will probably fulfill the requirements. This latter structure only applies to line C.

In addition to the first three structures common to lines C, F, and A Z, the latter location, line A Z, necessitates an unimportant structure approximately 5,000 northeast of Buena Vista on the ridge separating the waters of the Rio Aojeta and Agua Salud in order to support the summit level. The height of the ridge at that point was found to be approximately 90 feet above sea level. The length of this dam or wall will not exceed 700 feet.

Borings have not been made for any of these accessory structures, but from indications it appears that rock suitable for foundations will be found very near the surface.

BUENA VISTA LINE, TRACINGS 90 AND 103.

The last of the lines examined in the vicinity of Bohio is the Buena Vista location.

This line crosses the Panama Railroad at milepost 17, just above Buena Vista, intersects the canal axis at K 25.6, and connects with the high hills immediately adjoining on the left side of the Chagres Valley. On the right side the line runs into an abrupt bluff, caused by the railroad cut at milepost 17.

In some respects it is the most favorable location for a dam. The distance between 100-foot contours is less, elevation of bed rock sensibly higher, and the character of the foundation probably more satisfactory.

With the exception of one unimportant structure approximately 5,000 feet northeast of Buena Vista, which has been described under line AZ, additional work will not be necessary; the Gigante spillway and locks, of course, excepted.

Location of lock.—One condition which probably detracts greatly from the value of this location is the lock site. It is thought that a suitable location can be found, but in any event a modification in the alignment of the canal will be necessary.

It appears from a few borings made within the canal prism above and below the dam site that distance to foundation for the locks will not be found at prohibitory figures. Should that be the case a radical change of alignment below the dam will not be necessary.

On the other hand, if foundations for locks projected near the present canal prism immediately adjoining the dam do not prove satisfactory, it is quite certain that proper foundations do exist in the hills above Buena Vista. The latter location necessitates a change of alignment for some distance below the dam.

On the Buena Vista line the profile of bed rock has not been developed in detail across the entire valley, but it is thought that the lowest elevation of bed rock has been determined with reasonable accuracy.

Eleven borings were made on this section, all going to rock and extending into the latter several feet. The lowest elevation of bed rock suitable for foundation was found in hole 264 at -139.6. In the gorge, holes were spaced 33 feet apart, and it is not probable that depressions between adjoining borings will fall much below the lowest elevation reported.

LENGTH OF BUENA VISTA LINE.

Line Buena Vista is considerably shorter than either of the previous lines. The distance between 100-foot contours is approximately 1,270 feet, which is 57 feet shorter than line C and 1,431 shorter than line F.

The lowest elevation of bed rock was found at -139.6, which is approximately 25 feet above line C and 28 feet above the lowest plane of bed rock on line F.

With the exception of a well-defined layer of gravel approximately 15 feet in thickness near sea level, the material penetrated by the borings does not differ very much from conditions found on the other line. The greater portion of material in this section is sandy clay; but immediately overlying the rock the usual deposit of coarse water-bearing gravel, approximately 30 feet in thickness, was located.

In hole 260, located in the old canal excavation, a flowing well appeared when gravel was entered. Sixty-eight samples and 36.5 feet of core from borings taken on this line have been preserved for future reference similar to samples taken elsewhere.

ARTIFICIAL LAKE.

The area of an artificial lake formed by the Bohio dam has been estimated to be approximately 38.5 square miles. It is assumed that these figures are based on the F location for a dam. A dam on line C will reduce this area somewhat, but not sufficient to cause any serious alarm, but a dam either on line A Z or Buena Vista would reduce the area 1.6 and 2 miles, respectively. This would, of course, reduce the storage capacity of the reservoir very perceptibly.

It is believed that all possible locations in the vicinity of Bohio have been investigated, and from the information at hand it appears that line C presents the most favorable conditions over all other sites. The advisability of constructing a masonry dam or core wall on line A Z, it is thought, had never been considered. An earth-filled dam has been advocated by some on that location, but from the present knowledge of the material overlying the rock such construction, it appears, would be fatal. The material overlying the rock is extremely permeable, and with an 85 head the loss of water caused by leakage would seriously endanger the water supply, and the probable scouring effect underneath the fill might result in grave disaster, not only to the dam but to the construction below the same as well.

From the present light on the subject F can not be seriously considered as a proper location. Its only advantage lies in the increased lake area afforded.

The possible locations are therefore reduced to lines C and Buena Vista. On account of the impossibility of using the pneumatic process in preparing a suitable foundation at the depths encountered on both of the above sections, other means must be resorted to to effectually close the valley. If the latter can be accomplished at Buena Vista, satisfactory results on the C location are not excluded. It seems, therefore, that line C presents the more satisfactory condition of the two.

HISTORY OF CANAL AND BOHIO DAM.

The following is a brief history of the work leading to the construction of the Panama Canal, and more particularly its bearing on the Bohio dam, abstracted from the report of the Isthmian Canal Commission, 1899-1901, and information obtained elsewhere:

The first concession granted, authorizing "the construction of macadamized roads, railroads, or canals across the Isthmus, with the Pacific terminus at Panama," occurred in 1838, and the results following this grant were submitted to the French Government through M. M. Salamon, the leading spirit of the enterprise. In 1843 M. Guizot, minister of foreign affairs, instructed Napoleon Garella to proceed to Panama to report on same. The latter disappointed the expectations held by the projectors, no further steps were taken in the matter, and the concession was forfeited. During the following years more interest was manifested in the Nicaragua route. In 1850 Mr. Orville W. Childs was appointed chief engineer and charged with the survey of that route. Up to this time very little was known concerning the topography of the route via Panama, although a partial survey had been made in 1827 by Mr. J. A. Lloyd, who was commissioned by President Bolivar to survey the Isthmus of Panama. More definite knowledge concerning the topography across the Isthmus of Panama was secured from surveys in connection with the construction of the Panama Railroad, which was completed and opened to public use in 1855.

After the true nature of the country and obstacles to be overcome on the Nicaragua and Panama routes became apparent different locations were examined. These were confined principally to Colombia between Panama and the Atrato River, Tehuantepec in Mexico, and Nicaragua.

The first accurate information obtained concerning the Isthmus of Panama with reference to the construction of the canal was presented by Capt. Edward P. Lull and Mr. A. G. Menocal in 1875 after a careful instrumental survey. During the time these different routes were under discussion a provisional company was organized in France, and Lieut. L. N. B. Wyse visited the Republic of Colombia, representing the organization, and obtained a concession in 1878.

In 1879 an international congress of engineers, composed of delegates from different European nations, convened in Paris to consider the question of the best location for an interoceanic canal, and the Panama route was decided upon.

It was to be a sea-level canal.

This organization was known as the "Compagnie Universelle du Canal Interoceanique," and De Lesseps was at its head. The Wyse concession was purchased and operations began in 1883 and continued until 1899, at which date, for reasons which it will not be necessary to state, a liquidator was appointed, who secured the services of a commission composed of foreign and French engineers to report on the canal, and plans to be pursued in the future. After deliberate study and investigation, and a visit to the Isthmus, a report was rendered favoring a canal with locks and two levels, the first of locks on the Atlantic to be located at Bohio, the second at Bas Chispo, with a dam near Bohio, forming an artificial lake for the lower level, the summit level to be supplied with water from a reservoir constructed in the valley of the upper Chagres. Work on these lines was vigorously pursued. The possible objections resulting from a lock canal were not lost sight of, however, and plans were so laid that if the financial resources at hand and time allowed for the completion of the enterprise permitted, the upper level was to be omitted. This would do away with the upper locks and Bohio Lake would be the summit level.

After investigations vitally important to the design and safety of the structures supporting this plan were made and locations and conditions carefully considered, it was decided that the valley of the Chagres near Bohio offered the most favorable conditions for the location of the dam.

PREVIOUS BORINGS.

Numerous borings in the valley of the Chagres above Bohio were made and the site finally adopted is known and referred to in this report as line C. From records and maps obtained from the Panama Canal Company it does not appear that an accurate knowledge of the material overlying, character of and depth to proper foundations had ever been obtained. It is reported that an earth-filled dam was proposed, the base extending 26 feet below sea level. In order to verify the data secured from the Panama Canal Company, additional borings were made at this site (line C) by the Isthmian Canal Commission 1899-1901, and it became apparent at once that the only solution for a dam at that location necessitated a structure founded on rock for its entire length. The borings developed that the lowest elevation of rock suitable for foundation was at least 146 feet below sea level, which was deeper than it ever had been attempted to carry foundations.

Other more favorable locations were sought for. It was thought that line F, although considerably longer, offered more favorable conditions otherwise. From recent borings, however, it appears that the conditions on line F are less satisfactory than those on line C.

From all previous investigations it seems, therefore, that the most favorable location for a dam in the vicinity of Bohio is confined to two locations, namely, line C and Buena Vista, the former, line C, being the more favorable in the light of the present knowledge on the subject; and it appears from the information obtained concerning the character and conditions of the problem that if it should be imperative to further seriously consider the necessity of constructing a dam, the successful completion of one in the vicinity of Bohio has not been eliminated.

INVESTIGATIONS NOT RELATING TO BOHIO DAM.

The principal and most important duties assigned to the party stationed at Bohio pertained to borings and investigations of foundation for the Bohio dam, and the greater part of the expenditures incurred were devoted to that purpose. In addition, however, to these investigations extensive topographical surveys, discharge measurements of the Chagres, rainfall observations at Bohio, and a survey of the Panama Railroad from mile 11 to mile 24, approximately, were made.

The topographical surveys extend from approximately K 19 to K 25. Tracing 104 is a sketch showing the territory covered. The principal object of this survey was to verify the accuracy of existing maps, and also to locate machinery and railroad tracks abandoned in the field. In addition it is also of value in arriving at an approximate estimate of amount of work accomplished in the past and present conditions of same.

The original surveys platted on a scale of 1-2,000. Sheet 104 is a free-hand sketch taken from the original map.

The tangent projected for the Tiger Hill alternative line from Gatun to Bohio was located on the ground. This work was subsequently assigned to Mr. A. B. Nichols, assistant engineer at Gatun.

Daily discharge measurements of the Chagres River have been made at Buena Vista, using surface floats, and during periods of floods gaugings were also taken at Bohio. At the latter place these measurements were made, using a current meter.

Continuous records obtained by a self-registering gauge located at the Fluviograph Station immediately above Bohio, showing the fluctuations of the Chagres River, have been taken.

DAILY RAINFALLS.

Daily rainfall observations at this station have been made and recorded.

A tabulated statement pertaining to the daily discharge of the Chagres River at this station, and rainfall observations at Bohio, including the period covered by this report, is submitted herewith.

The survey of the Panama Railroad from mile 11 (42.86) to mile 23 (89.8) and an approximate estimate relating to double tracking that distance have been made and results submitted at a previous date.

All field books containing original notes and copies of notes have been indexed and a general index for the books has been prepared. All tracings have been numbered and indexed. During the period covered by this report, 111 tracings of different descriptions have been made out and filed away, and blueprints of the latter submitted as the work progressed.

There have been no cases of serious sickness among the members of this party, although most of them have had more or less severe attacks of malaria.

PERSONNEL OF PARTY.

With the exception of 4 men, who joined the party June 1, 3 of whom resigned, and 1 who was transferred, the personnel, with some additions as shown hereafter, remains unchanged.

APPENDIX D.

REPORT OF A. B. NICHOLS, RESIDENT ENGINEER, COVERING INVESTIGATIONS AT GATUN,
JUNE 1, 1904, TO FEBRUARY 28, 1905.

GATUN, ISTHMIAN CANAL ZONE, *April 19, 1905.*

Mr. W. E. DAUCHY,
Acting Chief Engineer, Panama.

DEAR SIR: I beg to submit herewith the results of borings made between Gatun and Bohio, in connection with Tiger Hill cut-off and Gatun dam site.

The drawings appended hereto, and the samples taken, show the nature of the ground along Tiger Hill cut-off pretty fully, but it may be proper to state that the rock found, until near Bohio, appears to be regular in its character, soft on the top and gradually getting harder until compact enough to core, although in some cases soft streaks appear in the hard rock.

I also call attention to the sand deposit between stations 262 and 335, which may give trouble in case a canal with locks at Tiger Hill and Bohio shall be adopted. Borings farther down the valley indicate that this sand deposit is not local.

Test borings to determine the feasibility of a dam at or near Gatun have been made (as shown on map, Appendix A) at various points in the valley from Gatun to above La Bruja. Wherever rock near the surface has been found, holes have been put down to determine whether it formed a subterranean ridge either in or across the valley.

The results are shown on the appended sections (Appendix F), except at La Bruja, where the high rock takes a circuitous course through holes Nos. 25, 31, 32, 34, 38, 49, 42, 30, 35, 44, and 2. The Chagres at La Bruja appears to have left the gorge, which here lies in the lagoon, and flows through a comparatively shallow gap in the rock.

The high rock extends down the right bank of the Chagres from hole No. 25, gradually decreasing in elevation (see hole No. 46 and No. 20) and dropping into the gorge between No. 20 and No. 9, as shown at No. 47.

The most favorable section is along an irregular line (sheet 2, Appendix F) crossing the valley a short distance above K. 12, and extending from the Tiger Hills to the ridge west of Rio Chagres through holes Nos. 49, 16, 48, 75, 12, 13, 14, and 15.

At hole No. 12 it catches the nose of the underground ridge of rock which outcrops above K. 13 and ends between hole No. 12 and holes No. 73 and No. 75.

The diamond drill was used in holes Nos. 13 and 14. At No. 13 the material in the bottom is a solid homogeneous volcanic rock showing a clean core. At No. 14 the sand is succeeded immediately by a hard, compact, basaltic rock.

The line of hills to westward of this section has no saddles less than +77 feet elevation. To the east, in the Tiger Hills between the French Diversion and the Panama Railroad, the surface is all above +55 feet except in one short saddle. At the Panama Railroad the 50-foot contours are less than 200 feet apart, with elevation of surface at lowest part of gap a little under +20 feet.

Another opening, which reaches to the valley of Rio Gatuncillo, occurs to east of stations 160-165 of Tiger Hill line (boring No. 158-25 is at station 158+25) 1,300 feet between 50-foot contours and surface elevation of +15 feet in the depression; and 4,400 feet northeast of Panama Railroad mile post 11, about 350 feet between 50-foot contours and elevation of +44 feet; and another across the swamp which extends from the valley of the Rio Chagres near Ahorca Lagarto to Rio Gatuncillo, with nearly 2,000 feet between 50-foot contours and surface elevation in swamp of about +20 feet.

The Tiger Hills (in which term I include the whole assemblage of hills from the French Diversion to the 2,000-foot swamp mentioned above) are a mass of rock. It outcrops in the beds of small streams even where the hills are quite low, and everywhere has about the same appearance on the surface. The probable nature of the whole mass is indicated by the borings made on the Tiger Hill cut-off.

The rock surface along Rio Chagres drops off below test hole No. 14 to -171.7 at No. 53, -204.7 at No. 59, -204.2 at No. 70, and -201.1 at No. 19-15. Test hole No. 71 shows the existence of a deep rock gorge under the Chagres diversion at Gatun. In the test holes no boulders have been encountered.

In the valley the material above the rock is composed of clay, clay mixed with sand in proportions varying from almost pure clay to nearly pure sand, some streaks of shells, and vegetation in sundry stages of decomposition.

The nature of the rock developed by these test holes appears to be identical with the mass of rock composing the Tiger Hills. It varies somewhat in hardness in different localities (due perhaps to the longer or shorter length of exposure before it was covered with silt), but almost always shows an increase of hardness the more it is penetrated.

The samples obtained have been arranged in trays and boxes. I hold them pending instructions for their disposal.

The appendices^a hereto are:

- A.—Map of 1-20,000 scale, 1 sheet.
- B.—Profile and section of borings, Tiger Hill cut-off, 18 sheets.
- C.—Tabulated statement of borings, Tiger Hill cut-off, 5 sheets.
- D.—Sections of test holes, 42 sheets.
- E.—Tabulated statement of test holes, 4 sheets.
- F.—Approximate sections of Chagres Valley, 10 sheets.

Respectfully,

A. B. NICHOLS, *Assistant Engineer.*

(Through the division engineer.)

^a These appendices (blue-prints) are on the files of the Commission, where they can be examined.

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