PROBLEMS OF THE PANAMA CANAL

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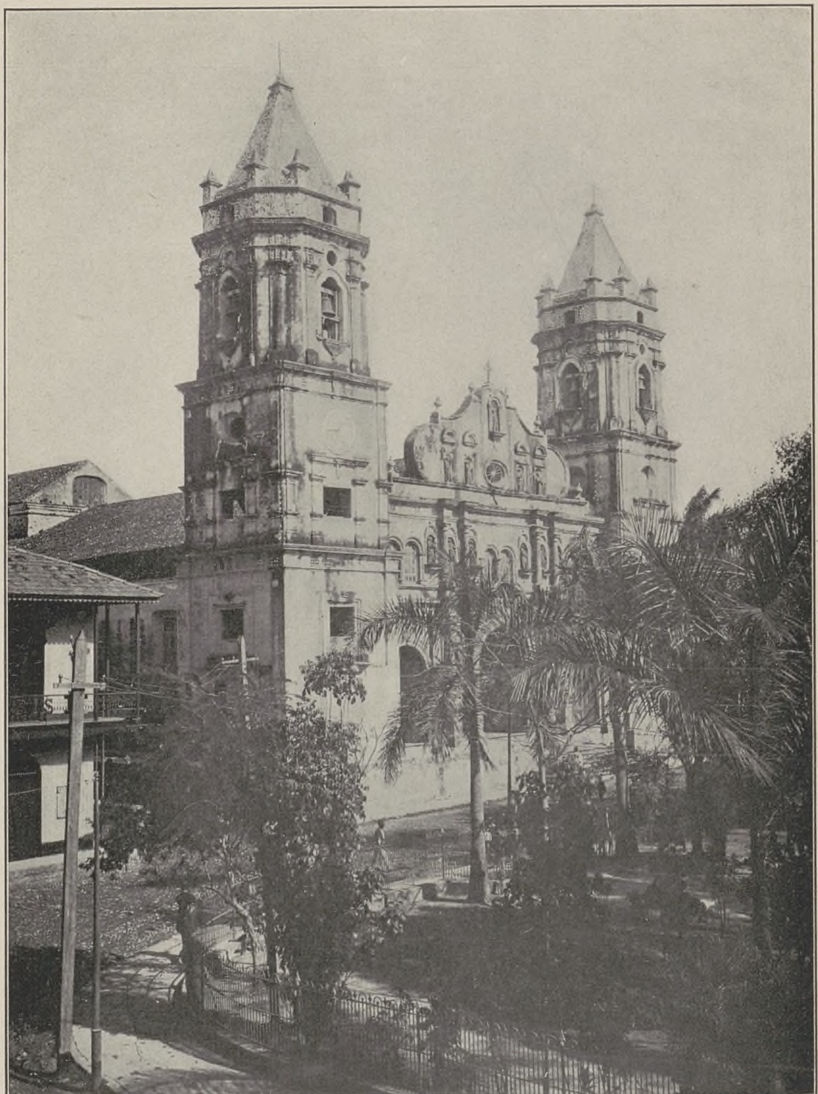

The Ancient Cathedral at Panama

PROBLEMS OF THE PANAMA CANAL

INCLUDING CLIMATOLOGY OF THE ISTHMUS, PHYSICS AND HYDRAULICS OF THE RIVER CHAGRES, CUT AT THE CONTINENTAL DIVIDE, AND DISCUSSION OF PLANS FOR THE WATERWAY, WITH HISTORY FROM 1890 TO DATE.

BY

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INTRODUCTION

The American public has had very little opportunity to acquire clear and correct information respecting the technical problems which confront us in undertaking the construction of the Panama canal. This matter has received the closest possible study since the work passed into the hands of the *"Compagnie Nouvelle du Canal de Panama"* in October, 1894. The official publications of this Company are in the French language and are little known in America. The following quotation from the final report of the Isthmian Canal Commission of 1899-01 shows how that body was impressed by an examination of these records when submitted for its inspection.

"The information relating to the topography, hydrography, and geology of the Isthmus is now much more complete than is usual before the inauguration of an engineering enterprise in a new country. The Canal Company spared no trouble or expense in laying it all before the Commission. The most important maps, drawings, and documents were lithographed or printed and systematically arranged for the use of the Commission, copies being furnished for each member. Many other documents were supplied in manuscript. In all some 340 documents, many of them elaborate studies, were furnished. A list of them will be found in Appendix C. These supplied essentially all the data required for the preparation of plans and estimates, though further information was desired as to the foundation upon which the great dam at Bohio must be built, and as to the area of the Chagres River drainage basin. This additional information was obtained by the field parties of this Commission. It was necessary also for the purpose of this investigation to verify the French data. Independent lines of levels, measurements of distances, borings, soundings, and hydrographic observations made by its own parties, supplemented by personal observation, enable this Commission to state that the data furnished by the Canal Company are essentially correct."

Having devoted about seven years to a technical study of the problem, with free access to the original note books, and aided by a thorough personal examination of the works on the Isthmus, it has seemed proper, now that my official connection with the engineering staff of the Company has ceased, to prepare an unbiased and truth-ful statement of how the work appears to a retired officer of the Corps of Engineers, United States Army, who has spent his life in the prosecution of public works confided to that Corps. This book sets forth these views.

My idea in preparing it has been to cover every essential element having a bearing upon the construction of the best possible canal. My thanks are due especially to the editors of *The Engineering Magazine* for permission to reproduce here certain statements and discussions of the technical elements of the problem which have appeared over my signature in that publication from time to time since 1901, and for the use of the reduction of the French map illustrating the higher variant of the Company, made for its issue of February, 1900. The magazine has exerted great influence among American engineers and statesmen in determining opinion as to the best route for the canal, and as to the proper treatment of the technical questions involved, and the courtesy in permitting these reproductions is highly appreciated by me. Similar acknowledgements are due to the editor of the *Monthly Weather Review* in regard to articles contributed to that journal treating of the climatology of the Isthmus, and to the editor of the *Harvard Engineering Journal.*

HENRY L. ABBOT.

WASHINGTON, D. C., January 16, 1905.

PREFACE TO SECOND EDITION

It has seemed desirable to extend this new edition to cover the progress of events since the transfer of the work to the United States, and at the same time to avoid confusion between the new and the old by too intimate an incorporation. This has been accomplished by adding a new chapter to the historical portion of the book; by explaining and discussing, under a new heading in chapter VII, the new projects resulting from the studies of the Board of Consulting Engineers appointed by President Roosevelt to advise as to plans for the canal; and by introducing recent and valuable climatological and hydraulic data at appropriate places in the text, but without combining them directly with the previous computations. By this plan all confusion is avoided, and comparisons between the two are rendered easy.

In a word, the new edition extends the history of the enterprise from the date of purchase through the preparatory period; explains the new studies and resulting plans for the canal, and the final action of the Government thereon; adds two and a half years to the climatological and hydraulic records, including a new and formidable flood of the Chagres; and describes the method adapted for the construction of the canal by contract, with the reasons therefor. The history and technology of the work is thus brought up to the beginning of the current year, 1907. The map of the French Company has been retained in preference to one showing the adopted project, because the large lake area on the latter obscures topographical details convenient for reference.

HENRY L. ABBOT.

WASHINGTON, D. C., February 1, 1907.

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CHAPTER I

THE NEW PANAMA CANAL COMPANY

Before proceeding to consider the technical questions involved in the construction of a canal crossing the Isthmus of Panama, a brief résumé of the recent history of the progress of events seems to be appropriate. The opening of the Panama Railroad early in 1855 had drawn special attention to this route as one favorable for a canal, and the Wyse concession from Colombia under which the Interoceanic Canal Company presided over by M. de Lesseps operated, bears the date of March 20, 1878. Work was practically begun in 1881 and ceased in 1888, under financial conditions so disastrous as to render its resumption a matter of great difficulty.

The affairs of the insolvent Company, under the general laws of France, passed into the hands of a receiver, M. Brunet, representing the stockholders, the bondholders, and the other creditors. He soon fell sick and died, being succeeded on March 8, 1890, by M. Monchicourt, who also died and was succeeded on March 14, 1894, by M. Gautron. The judgment of the court appointing M. Brunet, the *Tribunal Civil de la Seine,* was dated February 4, 1889. His first duty was to investigate the condition of the property, and to determine what were the proper steps to take in the interest of all concerned. With this object in view he proceeded to constitute a *Commission d'Etudes* to assist him by technical advice.

This Commission was selected from eminent engineers of France and other countries. As ultimately constituted it consisted of the following members, the first named being the president, and M. Nivoit, the secretary.

M. Guillemain, Inspector-General, and Director of the National School of Bridges and Routes of Communication.

M. Chaper, Engineer in the Corps of Mining Engineers.

M. Cousin, Engineer in the Corps of Bridges and Routes, of Belgium, and Professor in the University at Louvain.

M. V. Daymard, formerly Naval Engineer, Chief Engineer of the Transatlantic Steamship Company.

M. Descubes Du Chatenet, Engineer in the Corps of Mining Engineers.

M. Germain, Hydrographic Engineer of the Navy.

M. Holtz, Chief Engineer, and Professor in the National School of Bridges and Routes of Communication.

M. Lagout, Engineer in the Corps of Bridges and Routes of Communication.

M. Nivoit, Chief Engineer in the Corps of Mining Engineers, and Professor in the National School of Bridges and Routes of Communication.

M. Renoust Des Orgeries, Inspector General in the Corps of Bridges and Routes of Communication, retired.

M. Van Zuylen, Colonel of Engineers, and formerly Chief Engineer of the army of Holland in the East Indies.

This Commission assembled in October, 1889; sent, in December, a delegation of five of its members to the Isthmus thoroughly to examine the condition of the works on the spot; questioned many engineers and others who had knowledge of the operations; and consulted all the records and documents. After this careful technical study of the problem it rendered its report to the Receiver on May 5, 1890. This report contained among other valuable matter a project for the completion of a canal with locks, but this was submitted with the qualification that before actual work should be resumed on a large scale new examinations and investigations were necessary, as the data available were "far from possessing the precision essential to a definitive project." This advice of the *Commission d'Etudes* was followed by the Receiver, who at once took measures for the formation of a new company to undertake the work on these lines.

This task, under the conditions then existing, proved to be a slow and difficult undertaking, but the Receiver very wisely did not delay the taking of hydraulic observations upon the Chagres River, and the collection of other data which have proved to be of immense value in the subsequent technical studies.

Under such auspices the New Panama Canal Company was finally organized, on October 21, 1894, under the general laws of France. It had no relations with the Government of that country. It was purely a commercial corporation, with a charter reciting precise and definite agreements with the Receiver, who represented the interests of the creditors and investors of the old Company. This is called its *"Statuts"* and has the force of law for those concerned.

In general terms these *"Statuts"* stipulated that the New Company should raise the sum of at least sixty-five million francs and proceed to investigate the problem of the completion of the canal, receiving in aid thereof the material assets of the old Company upon conditions relative to future profits satisfactory to both parties. When about half of the new capital should have been expended a special commission should be appointed to report upon the results of the investigations and work already accomplished, and upon the conclusions to be drawn therefrom as to further operations. This commission was to consist of five members, two to be nominated by the Receiver, two by the Board of Directors of the New Company, and the fifth, who should be president, to be chosen by the other four members. When their report had been received and published a general assembly of the stockholders of the New Company should be called to determine upon the question of ways and means for the completion of the canal, always of course, under the conditions as to benefits set forth or implied by the *"Statuts."* These conditions in brief were that when the canal should be completed and opened to traffic sixty per cent. of the net profits should inure to the liquidation and forty per cent. to the New Company. It was further stipulated in the *"Statuts"* that to assist the New Company to form a definite technical project for the completion of the canal the Board of Directors of the New Company should be authorized to appoint a *Comité Technique* consisting of "experts in matters of public works, and notably of retired inspectors-general of the Corps of Bridges and Routes of Communication"—the selection and numbers of this body being left to the discretion of the Board. It is needless to refer here to the professional standing of this famous Corps of French Government Engineers whose works are studied the world over.

From the outset it had been the intention of the Board of Directors to constitute the *Comité Technique* upon an international basis, in view of the fact that when it became time to raise funds for resuming work upon a large scale its purpose was to appeal to the moneyed centers of the world, and it would be important to command general confidence in its project and technical estimates. At first, however, the duties of this body of engineers would be chiefly to advise as to the collection of the needful data upon which to begin the final study, and the seven French members were promptly appointed. The seven foreign members were soon added, and the membership as finally constituted was the following; the first named being the president, and the second the secretary:

M. Robaglia, Inspector-General of the Corps of Bridges and Routes of Communication, retired.

M. Bouvier, Inspector-General of the Corps of Bridges and Routes of Communication, retired.

General Abbot, Colonel of the Corps of United States Engineers, retired.

M. Castel, Inspector-General of the Corps of Mines, retired.

M. Dayard, Chief Engineer of the Transatlantic Steamship Company.

M. Fargue, Inspector-General of the Corps of Bridges and Routes of Communication, retired.

M. Fteley, Chief Engineer of the Aqueduct Commission of New

York City, and Past President of the Society of Civil Engineers.

M. Fulscher, Consulting Engineer of the Ministry of Public Works of Prussia, and formerly Chief Engineer of the Kiel Canal.

M. Hersent, Civil Engineer, constructing the new docks at Antwerp.

M. Hunter, Chief Engineer of the Manchester Ship Canal.

M. Koch, Consulting Engineer of Public Works, Director of the Technical Academy at Darmstadt. Formerly Technical member of the Imperial Commission of the Kiel Canal.

M. Jules Martin, Inspector-General of the Corps of Bridges and Routes of Communication, retired.

M. Skalkowski, formerly Director of the Department of Mines in the Ministry of Agriculture and State Property of Russia.

M. Sosa, Chief Engineer of Colombia (graduate of the Troy Polytechnic Institute, New York).

The Director-General of the New Panama Canal Company, and later its President, M. Maurice Hutin, was a member of the Corps of Bridges and Routes of Communication of France; as was also its Chief Engineer, M. Louis Choron, charged with conducting the investigations and the works of construction on the Isthmus. Both were present and took part in all the discussions of the *Comité Technique*. They were supported by an able engineer staff in prosecuting the studies on the Isthmus, and in working out the final plans and estimates.

Under these conditions the work proceeded up to the time of the outbreak of our war with Spain, in 1898. The primary object of the New Company, while taking care that the excavations in progress should be made only where they were certain to be included in any possible plan of ultimate completion, was to collect full data for determining the best possible project for the completion of the canal. Any question which was raised by the studies of the *Comité Technique* was promptly settled by special surveys and measurements ordered upon the Isthmus. The results were becoming daily more and more satisfactory, but there was no blowing of trumpets or public advertisement of the work. Although aware that the Maritime Canal Company was actively laboring to secure funds from the Congress of the United States in favor of the Nicaragua route, the Board of Directors of the New Company were so fully convinced that a canal by that route could never seriously compete with their own that they gave little attention to these efforts of a private company to raise funds to construct a parallel and rival line. The final report of the *Comité Technique* was completed, and signed unanimously, on November 16, 1898; but the body remained in further consultation with the Company until July, 1900. The estimated cost of completing a canal that would amply meet all the needs of commerce and would be completed in about ten years was about one hundred million dollars. Detailed plans for its construction were set forth in the report. The Manchester Ship Canal and the Kiel Canal had both been carefully inspected during the progress of the studies.

About half of the capital of the New Panama Canal Company having been expended at this period, the Commission of five members contemplated by the "*Statuts*" was appointed. The membership was the following, M. Etienne being president:

M. Paul Etienne, Chief Engineer of the Corps of Bridges and Routes of Communication.

General H. L. Abbot, Colonel of the Corps of United States Engineers, retired.

M. Joseph Barba, formerly Engineer in the French Navy, and Chief Engineer at the Iron Works at Creusot.

M. Marcel Bertrand, Member of the Institute of France, Chief Engineer in the Corps of Mines, and Professor of Geology at the National Higher School of Mines.

M. Philippe Zurcher, Chief Engineer of the Corps of Bridges and Routes of Communication.

Early in 1898 this Commission made a thorough inspection of the works on the Isthmus, and of the records and studies at Paris at the offices of the New Company, and on February 28, 1899, rendered its final joint report to the Receiver and to the Board of Directors of the New Company. The following extract sufficiently indicates its unanimous conclusions:

"In fine, the investigations for the completion of the canal have been conducted in a practical and scientific manner, and upon the most judicious methods.

"The basis on which the project rests has been established by actual experience, and by precise observations upon existing conditions, which the old Company began and which the New Company has completed and rectified with the greatest care. The precision of this basis is then certain.

"The three solutions presented meet equally the needs of commerce and are feasible, from a technical point of view, under the conditions of time and expense contemplated, and with the means of execution heretofore in use on the Isthmus. There are, however, good reasons to believe that these means can be sensibly improved when the time comes to begin work, by resorting to improved apparatus and by better dispositions for operating upon a large scale.

"Consequently the Commission is of the opinion that the adopted project is practicable under the conditions of time and expense indicated, and that the New Company has demonstrated that by works which will not exceed an outlay of about one hundred million dollars, and a duration of about ten years, it is possible to open the Panama Canal to extensive commerce, to remove the obstacle which the Isthmus opposes to international communication, and thus to complete an immense work that interests all the nations of the world and is the greatest which human genius has ever planned."

Perhaps this is the place to refer to certain groundless statements that have been reiterated both in Congress and in the public prints concerning the objects and methods of the New Panama Canal Company. Having soon after my retirement from active service in the Corps of Engineers been invited to serve as a member of the *Comité Technique,* and having further been chosen by the Board of Directors of the New Company to be one of their two representatives on the Commission contemplated by its *"Statuts,"* and having continued to be its consulting engineer, from the adjournment of these bodies up to the final transfer of its property to the United States, with a view to continue the study of new technical data collected upon the Isthmus relative to the Chagres river and to climatology, I am in a position to know the truth. It is certain that the New Company, when organized, had no intention or wish to sell their rights on the Isthmus. Their object was first to secure for the completion of the canal a thoroughly well established project and estimate which would command the confidence of the financial world, and then to proceed to raise funds for this object by demonstrating that the investment would be judicious and worthy of the attention of capitalists. The mistakes of the old Company would thus be repaired and the losses of the early investors, so far as practicable, would be made good. This object, which was neither more nor less than the prompt completion of the canal, was that for which both the Receiver and the New Company had coöperated, and which they had done their best to bring about from the beginning to the end. It was the insistence of our Government upon securing the absolute ownership and control of the canal, and not any plan of the New Company, that led to the final sale.

If matters had continued as before it is my belief that the canal would have been completed on these lines. But when our war with Spain occurred, and the passage of the battleship Oregon round Cape Horn drew the attention of the entire American people to the importance of an Isthmian route of communication, wholly new conditions were developed. It was no longer a question of competing with a private company, struggling at Washington to raise funds to construct a parallel canal. Well understood natural conditions made the Nicaragua route so inferior to their own that, even if completed, successful commercial competition was believed to be impossible. But if the newly awakened popular demand for a canal should induce the American Government to undertake the work, the New Company would be brought face to face with two formidable conditions,—the difficulty in raising funds for the completion of the Panama canal would be greatly increased if the parallel route were supported by the boundless resources of the

United States, and what was of hardly less importance, the question of labor to complete the construction would be greatly complicated. Experience had demonstrated that this labor must come in great part from the negroes of the West Indies, who alone are well fitted to perform hard labor under the tropical sun of the Isthmus, and with two canals under construction at the same time competition would raise the price to a ruinous extent. Knowing that the favorable conditions created at Panama by the New Company were neither appreciated nor known in the United States, and well satisfied that if known it would be for the interest of the latter to assist rather than to retard the completion of the Panama canal, the Board of Directors decided to transmit to the Department of State at Washington the recently completed report of the *Comité Technique,* embodying the adopted technical project, together with an offer to explain in detail the exact condition of the work before any commission of engineers or others that might be selected for the purpose. This report, with a letter of M. Bonnardel, President of the Board of Directors, signed at Paris on November 18, 1898, was placed before the State Department, and through it in the hands of President McKinley, on December 2, 1898. On the 21st of that month the Senate passed a bill to aid the Maritime Canal Company in the construction of a canal by the Nicaragua route, by the large vote of 48 yeas to 6 nays, but it failed to receive action in the House before adjournment. The object of the New Company was simply to protect itself by securing a hearing in which it could present the merits of its route, before a final decision in ignorance of the new conditions at Panama had been made in favor of its rival. This opportunity was afforded by an amendment of the Senate, in favor of Nicaragua, added to the River and Harbor bill. This brought that bill again before the River and Harbor Committee of the House, and the representatives of the Company were accorded a hearing on February 27, 1899. The Director-General, M. Hutin, was present, and the technical exhibit, together with his statement that the Company was authorized by the terms of its concession from Colombia, and was willing to reincorporate as an American Company under American laws if its route should be preferred, probably led to the rejection of the Senate amendment and ultimately, on March 3, 1899, to the adoption by Congress of a compromise by which the President was authorized and empowered to make full and complete investigations to determine the most practicable and feasible route for an Isthmian canal, with the cost of constructing the same and placing it under the control, management, and ownership of the United States. President McKinley, in pursuance of the provisions of this Act, placed these investigations, including all elements required for his own guidance and for the final action of Congress upon the subject of the location and construction of the canal, in the hands of a Commission of which Admiral Walker was chosen president. The membership of this Commission was the following, as described in their official report:

Rear-Admiral John G. Walker, United States Navy, retired.

Hon. Samuel Pasco.

Mr. George S. Morison.

Lieutenant-Colonel Oswald H. Ernst, Corps of Engineers, United States Army.

Lewis M. Haupt, Civil Engineer.

Alfred Noble, Civil Engineer.

Colonel Peter C. Hains, Corps of Engineers, United States Army.

William H. Burr, Civil Engineer.

Prof. Emory R. Johnson.

Upon an invitation of the New Company a delegation of six members of this Commission proceeded at once to Paris and devoted nearly a month in August and September, 1899, to a careful examination of the plans and technical details of the projected canal, and of the other questions connected therewith. As already stated, the wish of the New Company was by no means to sell its rights on the Isthmus, as moreover was expressly forbidden by the terms of its concession from Colombia, but to reincorporate as an American Company and complete the construction with American assistance, according full control by giving a majority vote on its Board of Directors. This plan was not in accordance with the provisions of the law under which the Commission was acting, which called for absolute ownership of the canal, a legal condition that rendered it necessary for the Company to open long and tedious negotiations with Colombia to secure its consent to the abrogation of a clause of the concession forbidding under pain of forfeiture, the transfer to any foreign Government. Hence no agreement was possible at that time, and the Commission proceeded to make the careful local examinations on the entire Isthmus, called for by its instructions.

It was only in the spring of 1901, upon the arrival at Washington of the Colombian Minister Plenipotentiary, that the Company could obtain an official declaration to the effect that, with certain restrictions of a political nature, the Government of Colombia would authorize the transfer of the concession to the United States. Looking to this the Minister did authorize the negotiations necessary for that purpose, coupled, however, with the request that he be informed what such conditions would be on the part of the Company. To this request due response was made in a letter dated May 1, 1901; and this response was communicated by the Minister to the President of the Commission, thus officially bringing the subject before it. Admiral Walker thereupon addressed a letter dated May 8, 1901, to M. Hutin, then President and Director-General of the New Company, who was in the United States. This letter renewed three questions previously asked but heretofore unanswerable on legal grounds, as explained above. These questions in brief were: Is the New Panama Canal Company willing to sell to the United States its rights and property? Has the Company the legal right and power so to do, particularly as concerns the liquidation of the old Company? And third, for what sum in cash will the Company make the transfer?

The President of the New Company replied on May 15, 1901, to the effect that, with the authorization of the Colombian Government, the Company would consent to the transfer, limiting, however, the term of this engagement to March 1, 1902 (subsequently extended to the end of the approaching session of Congress, at the request of the President of the Commission). To the second question he replied that the Company, in fact and in law, had the right to give a legal and clear title to the property. The third question was less easy to answer categorically. The publication of the preliminary report of the Isthmian Canal Commission (on November 30, 1900) had made known that the estimate placed on the value of the property by the Commission was incomplete and inexact. Furthermore, in justice to all parties where so many different elements entered the question, a lump sum could not clearly and satisfactorily set forth the claims of the Company. The Commission had stated that it had "no authority to accept or reject any terms which may be offered, but is collecting information to be submitted to the President." The matter, therefore, must ultimately come before Congress for decision, and that body confronted by two different lump estimates might well make ill-founded and unjust reductions from the lack of definite information. Hence it was obligatory in justice to the stockholders that their agents should establish the basis for a reasonable and fair valuation. This it seemed proper to do by requesting that the true value of its works and of each of its properties should be determined by applying ordinary business methods. For these reasons the answer of the President of the Company to the third question took the form of the following proposition, in substance:

The purchase price to be established between the Commission and the Company as far as possible upon elements determined by friendly discussion; but, if notable differences of opinion were developed, by arbitration in the usual form. The preliminary understanding to be reached prior to December 1st, that is to say, before the assembling of Congress, so that the figures after having been approved at a General Meeting of the stockholders of the New Company, could be authoritatively presented to Congress at the approaching session. This price would represent the maximum of the Company's demands, and would bind the latter, although of course it could not bind Congress.

The President of the Commission replied to this letter on May 16, 1901, making no fundamental objection to applying the plan proposed.

The Company at Paris immediately entered upon the preparation of a classified list of its different properties, and the results in the form of a memorandum were placed in the hands of the Commission on October 2, 1901, followed a few days later by a letter from the President of the Company, dated Paris, October 4, in which it was stated:

"These are only the amounts to which we have come from a personal estimation of the elements to be mutually discussed pro and con in our negotiations, and which as a result of such discussion might be altered in a more or less important degree. This is, therefore, properly speaking the first expression of the views of our Company, to which you have referred in your letter of May 16th last, as being to form the basis of discussion on our side in the proposed negotiations, which negotiations we shall take up, as you may be sure, with the most earnest wish to reach an amicable understanding. With that object in view, we are willing to follow a sincere course of conciliation and concessions, with the hope that we may be met from the other side with the same spirit and the same desire to conciliate in an equitable manner the weighty interests which are confronted in the subject."

At first verbally, and later in a letter dated October 18, 1901, the President of the Commission declined to mutually discuss pro and con the figures and valuations contained in the memorandum, demanding a valuation in a lump sum of the properties without any reserve whatever; offering, however, to transmit in the final report any proposition the Company might desire to submit.

The New Company thus found itself cut off from any opportunity, believed to have been granted by the Commission's letter of May 16, 1901, to explain in detail the estimated value of its properties. Furthermore, in a letter dated November 5, 1901, the President of the Commission indicated that he proposed to regard the prices, which the New Company had offered merely as bases for discussion, as constituting when summed up a definite lump sum which the Company intended to demand for its property. Against this view the President of the Company protested vigorously in a letter dated on the following day, reasserting that the memorandum represented simply the estimates, believed to be correct and just, which the Company had submitted for discussion and upon which it was prepared to make reasonable concessions.

The final report of the Isthmian Canal Commission, dated November 16, 1901, ignored this protest, and presented the total of the several elements of the memorandum as the "total amount for which the Company offers to sell and transfer its canal property to the United States." In figures this summation amounted to $109,141,500, the valuation of the Commission being $40,000,000. It may be added that when the property passed from the insolvent old Company into the hands of the Receiver appointed by the *Tribunal Civil de la Seine,* the valuation was about $90,000,000, and the New Company since that date had expended several millions. The actual outlay had been vastly greater.

The closing sentence of the final report of the Isthmian Commission reads as follows:

"After considering all the facts developed by the investigations made by the Commission and the actual situation as it now stands, and having in view the terms offered by the New Panama Canal Company, this Commission is of opinion that 'the most practicable and feasible route' for an Isthmian Canal, to be 'under the control, management, and ownership of the United States' is that known as the Nicaragua route."

When this final report became known at Paris the President and members of the Board of Directors (or some of the latter) resigned, and a General Meeting of the stockholders, held on December 21, 1901, approved a resolution to negotiate on the terms estimated by the Commission. The new President of the Company telegraphed an offer to sell the property for $40,000,000, and the Isthmian Canal Commission rendered a supplementary report, dated January 18, 1902, in which is stated:

"The unreasonable sum asked for the property and rights of the New Panama Canal Company when the Commission reached its former conclusion overbalanced that route, and now that the estimates by the two routes have been nearly equalized the Commission can form its judgment by weighing the advantages of each and determining which is the more practicable and feasible."......"After considering the changed conditions that now exist, the Commission is of opinion that 'the most practicable and feasible route' for an Isthmian Canal, to be 'under the control, management, and ownership of the United States' is that known as the Panama route."

Such, in brief, was the course of events by which the United States secured the right to purchase the concessions and properties of the New Panama Canal Company, at a price which the Company believed to be certainly much below its intrinsic value. The fact that it had the requisite legal right to make the transfer had already been established by official American researches at Paris. It only remained for Congress to act.

Without waiting for the report of the Isthmian Canal Commission the House had passed, by a vote of 223 yeas to 25 nays, what was known as the Hepburn Bill, authorizing the President to acquire the right to construct a canal by the Nicaragua route, and to proceed to the actual construction. The sum of ten million dollars was appropriated, and contracts for materials and work aggregating one hundred and forty millions more were authorized. Numerous hearings were held before the Senate Committee on Interoceanic Canals, in which the engineer members of the Commission reaffirmed even more strongly than in their official reports their belief that from an engineering point of view the Panama route was greatly superior to that by Nicaragua. An extended debate followed in the Senate, in which Senator Hanna presented the results of a personal investigation of the problem of the routes. He had prepared a description of the two canals as projected by the Isthmian Canal Commission, and a series of questions designed to develop their relative merits from a practical point of view. These he had submitted to eighty shipowners, shipmasters, officers and pilots operating the most important intercontinental steamship lines, and sailing vessels engaged in coastwise trade. The answers were unanimous in favor of the Panama route, and ten of these votes were given by parties interested in and familiar with the handling of sailing ships. Full details of the questions and answers will be found in the Congressional Record of June 9, 1902. Many other noteworthy speeches were made.

After this extended debate in the Senate an amendment to the pending bill was offered by Senator Spooner, striking out all after the enacting clause and inserting what ultimately took the following shape. The President to be authorized to acquire for a sum not exceeding $40,000,000 the rights and property of the New Panama Canal Company and, by treaty with Colombia, the perpetual control of the strip of territory needful for operating the canal, and to pay for the same the sum requisite for both purposes; and then to proceed to complete the work under an Isthmian Canal Commission consisting of seven members, to be nominated and appointed by the President. A sum of $145,000,000 was pledged. This amendment was adopted by a vote of 67 yeas to 6 nays on June 19, 1902; and the bill passed the House of Representatives by a vote of 259 yeas to 8 nays on June 26, 1902, duly receiving the approval of the President.

To carry this law into effect the Hay-Herran treaty with Colombia was signed on January 22, and ratified by the United States Senate on March 17, 1903, but failed of ratification by the Colombian Congress. A revolution upon the Isthmus of Panama followed early in November, 1903, by which that State resumed its independence and adopted a republican form of government. The Hay-Bunau-Varilla treaty was negotiated with the new Republic on November 18, 1903, by which the United States secured all rights upon the Isthmus needful for the construction and operation of an interoceanic canal; and this treaty was duly ratified by both governments on February 26, 1904. Thus were definitely settled both the choice of the route and the necessary legal preliminaries to the construction of the canal by the United States. The payment of the funds to the New Panama Canal Company and to the Republic of Panama followed in due course, and the work was at once inaugurated.

CHAPTER II

THE CANAL UNDER CONTROL OF THE UNITED STATES

Under the Act approved June 28, 1902, authorizing the construction of the canal the President, after the needful diplomatic and financial preliminaries had been terminated, and acting through an Isthmian Canal Commission of seven members, was charged with the construction of the interoceanic waterway and commodious terminal harbors, and with making provisions for the protection of the same.

This Commission was appointed on February 9, 1904, was confirmed by the Senate on March 3, and held its first meeting on March 22. Its membership was the following, Admiral Walker being its president:

Rear-Admiral John G. Walker, U. S. Navy, retired.

Major-General George W. Davis, U. S. Army, retired.

William Barclay Parsons, of New York.

William H. Burr, of New York.

Benjamin M. Harrod, of Louisiana.

Carl Ewald Grunsky, of California.

Frank J. Hecker, of Michigan.

Mr. Hecker resigned on November 16, 1904, and his vacancy was not filled.

Legislation for the provisional government of the Canal Zone was enacted by Act of Congress approved April 28, 1904. This Zone consists of the land and water contained in a belt ten miles wide extending from a point three marine miles from low water mark in the Caribbean Sea to a like distance in the Pacific Ocean, together with a group of four islands in the Bay of Panama, and such other lands and waters convenient for canal uses as are granted by the treaty with the Republic of Panama. Under this Act the President was charged with vesting the government of the Zone in such person or persons and under such regulations as he might direct. By his letter of instructions of May 9, 1904, the President charged the Isthmian Canal Commission with the government of the Zone as well as with the construction of the canal, both of these duties to be carried on or exercised under the direction of the War Department. General Davis was appointed Governor.

These joint duties of the Commission covered a wide range, to wit: the making of the surveys and investigations and the preparation of the needful plans and specifications; the supervision of the execution of all engineering, hydraulic, and sanitary works required; the enacting of all needful legislation for the government of the Zone, and for the administration of its military, civil, and judicial affairs; the establishment of a civil service based on a merit system; the procurement by purchase or expropriation of all needful lands and, after due advertisement, of all kinds of engineering and construction appliances; and finally the economical and correct disbursement of all canal and administration funds. To these duties would accrue those of directors of the Panama Railroad (the United States having become owner of about 69|70 of its shares) and of its administration in a manner to make it an adjunct to the construction of the canal, and a route of commercial movement across the Isthmus.

The purchase of the property of the New Panama Canal Company having been duly completed, Messrs. Day and Russell, representing the Attorney-General of the United States at Paris, instructed Lieut. Mark Brooke, Corps of Engineers, then representing the United States and the Canal Commission upon the Isthmus, to take possession of the property. This was done on May 4, 1904. His instructions from the Commission were to continue operations with the employees that had been working under the French Company. This he did until superseded on May 17 by the arrival with full powers of Governor Davis, who continued the work.

Meantime the Commission had devoted its attention to preparations for exercising the extensive jurisdiction confided to its charge. Its first visit to the Isthmus was made on April 5, a month before the transfer of the property, when a study of the French operations and current methods of work was made; and further examinations at Colon, Gatun, Bohio, and the Upper Chagres valley, in connection with ultimate plans for the canal, were projected and were inaugurated in May. Colonel Gorgas and other medical experts accompanied the Commission at this visit, and were thus prepared to begin to organize an efficient health department at the very outset.

For the performance of its multifarious duties the Commission divided itself into six committees,—one on engineering plans, one for executive work, one on engineering, one on finance, one on legislation, and one on sanitation. The chairman of the Commission was *ex officio* a member of each committee, as was also General Davis, Governor of the Zone, when meetings were held on the Isthmus.

The most pressing duty of the Commission was to establish a classified organization on the Isthmus suited to deal with problems involving accounting, material on hand, machinery, supplies, recruiting of labor, etc. Then followed the political conditions of the Zone government, which demanded prompt attention inasmuch as under the terms of the Act the legislative power of the Commission over the Zone would cease when the Fifty-eighth Congress expired on March 4, 1905. It proved to be no sinecure, as will be appreciated from the fact that between August 16, 1904, and March 1, 1905, twenty-four laws were enacted "by authority of the President of the United States" covering: organization of a judiciary, notaries public, suppression of lotteries, prohibition of gambling, temporary alcaldes, expropriation, municipal governments, executive branch, sanitary regulations, quarantine regulations, legal holidays, penitentiary, officers of courts, penal code (18 titles), criminal procedure (15 titles), salaries of certain officers, administration of certain estates, and seven Acts amendatory of above. These Acts cover 136 octavo pages of small type in the two annual reports.

The Panama Railroad administration involved other difficult problems for the Commission. Being a Company chartered (in 1849) by the State of New York it was legally necessary to administer it through a board of directors; and this had caused the nomination of the members of the Commission to represent the shares owned by the Government. The outstanding shares were promptly acquired by purchase, but in the absence of special legislation by Congress this administration through a board of directors is still obligatory. When the ownership passed to the Government the transit route consisted of 47.65 miles of single track road between Colon and Panama, with 26.07 miles of sidings; the road bed was in good condition but considerable repairs were needed both in track and equipment. Much land and many buildings were also owned by the Company, together with a line of steamers running to New York, but the dockage facilities were altogether inadequate for the new demands. The management of the road both as a route of commercial transit between oceans, and as a vital agency in the construction of the canal, imposed complex problems upon the Commission.

Mr. John F. Wallace was elected Chief Engineer by the Commission on May 6, 1904, and was duly appointed under date of June 14, to take effect on June 1. He arrived on the Isthmus on June 28, accompanied by Colonel Gorgas charged with the sanitary administration.

Mr. Wallace found a few hundred men at work on the Culebra cut under Major William M. Black of the Corps of Engineers; and, in progress of execution, the technical investigations ordered by the Commission at Colon, Gatun, Bohio and on the Upper Chagres. He directed his attention to continuing these works and, in succession, to the organization of his staff; to the repair of the old buildings and the erection of new; to the water supply and sewerage problems; and to making requisitions for steam shovels and other important supplies. Later, on April 1, 1905, he was duly elected vice-president and general manager of the Panama Railroad, having performed the latter duties for some weeks, under protest at occupying a subordinate position. Indeed from his testimony before the Senate Committee on Interoceanic Canals it appears that from the outset he chafed vigorously against supervision in his canal duties, and at the delays inherent to the inauguration of governmental operations so far removed from the base of supplies.

It will be noted that prior to the adoption of a definite type of canal in June, 1906, the only work involving actual construction was carried on at the Culebra cut where, with a view to secure data for estimating the unit cost of excavation, operations on a small scale were begun with the French excavators and appliances during the last six months of 1904. The latter were gradually replaced with American steam shovels, the first being installed on November 11, 1904, and the last excavator being discarded on June 16, 1905. Early in August, 1905, when 11 steam shovels had been put at work, the necessity of using the laboring force and plant elsewhere in preparing routes to new dumps caused this experimental work to cease. The actual cost of excavation per cubic yard in place, computed upon the basis of outlay to a contractor, is shown in the following table: It was 53.4 cents in 1904, 91.6 cents in 1905, and 77.6 cents in 1906—average 78.4 cents.

Month	Output in Yards	Cents per Yard
July, 1904.	31,599	64.5
August	35,056	50.2
Sept.	25,220	55.9
Oct.	19,695	52.5
Nov.	28,860	47.4
Dec.	42,935	50.1
Jan., 1905.	70,650	47.8
Feb.	75,200	46.5
March	132,840	43.3

Month	Output in Yards	Cents per Yard
April	126,749	52.5
May	75,935	83.8
June	76,905	102.7
July	78,570	103.5
August	49,210	153.9
Sept.	41,885	144.1
Oct.	52,940	123.0
Nov.	60,540	105.0
Dec.	70,630	93.0
Jan., 1906	120,990	72.0
Feb.	168,410	61.8
March	240,000	53.5
April	313,177	65.3
May	194,645	77.6
June	207,760	81.0
July	157,093	99.6
Aug.	244,844	87.1
Sept.	291,450	74.8
Oct.	325,835	72.6
Nov.	221,642	98.8
Dec.	278,197	87.0
Jan., 1907	566,750	57.2

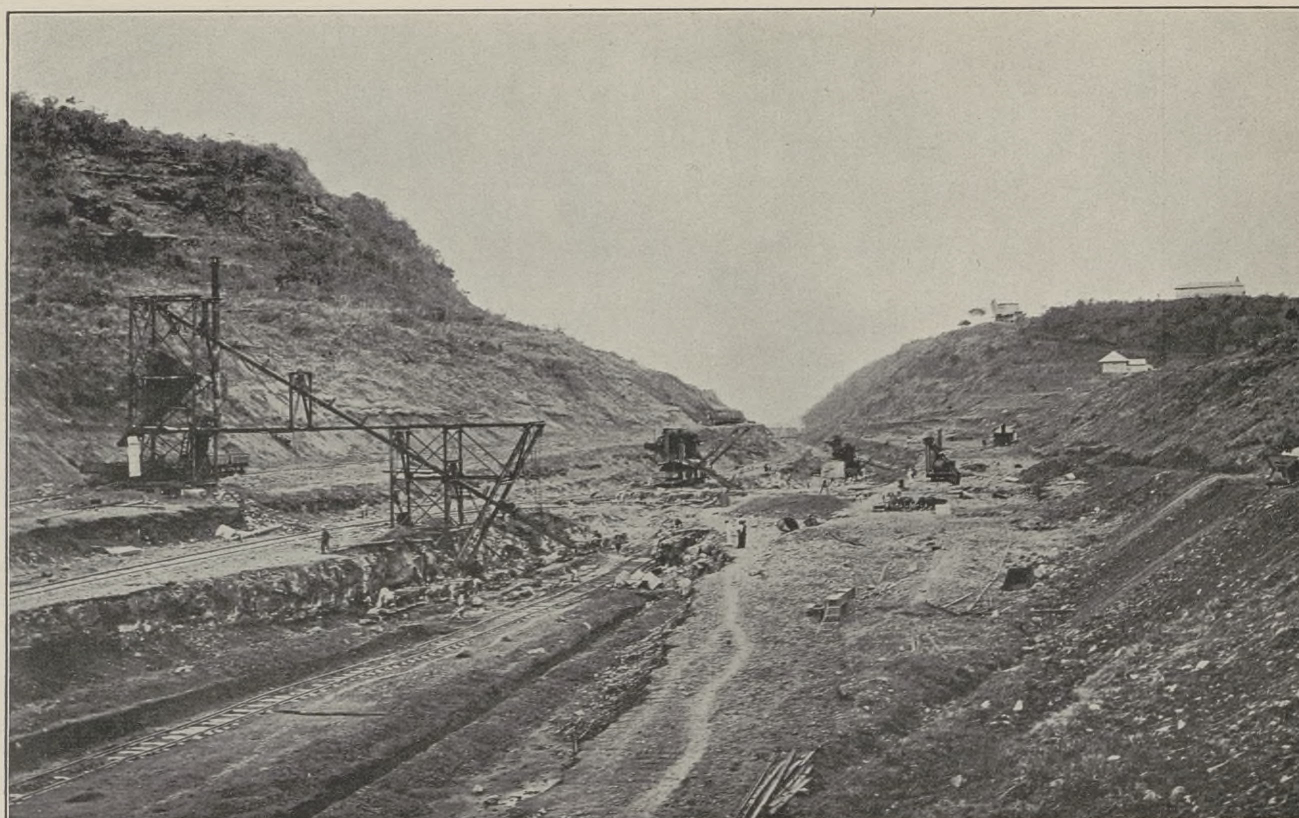
In considering this table it is to be noted that the decision of the Attorney-General, taking effect on June 1, 1905, that the eight-hour law extended to the Isthmus (shortening the hours of labor 20 per cent. without reduction of pay), together with the use of different plant at different dates and, what is still more vital, the fact that the excavation had not reached a depth to develop fully the difficulties and delays resulting from unavoidably having to transport the spoil to distant dumps, tend largely to deprive the resulting unit prices of any safe application except perhaps to a lock canal of high summit level. The estimates of the *Comité Technique,* varied from 52 to 81 cents according to the material encountered in the cut; that of the Isthmian Canal Commission of 1899-01 was fixed at 80 cents. If these new data prove anything, they must be regarded simply as confirmatory of those previous valuations of probable cost, neither of which contemplated excavation below a summit level of 65 feet.

For example, the following records were kept soon after the New

Panama Canal Company began operations, and were laid before the *Comité Technique* in December, 1897. Their object having been to secure data upon which to base estimates, a separate record of sixteen classes of expenditure was preserved, such as blasting, excavating and loading, transporting and dumping, preparing and maintaining tracks, repairs of plant, cost of coal, explosives, and other materials, mining in the gallery at the Culebra and operating the cableways at Emperador, etc. The sum of each item divided by the total number of cubic metres excavated would indicate its proportional cost, and the aggregate would show the total cost per cubic metre. The following figures present the final results, transformed into cubic yards and American currency. During the year 1896 the volumes excavated were estimated in place; and in 1897 in bulk deducting 10% for excess. The higher cost in the Emperador section is probably explained by the larger percentage of hard rock, as is doubtless the case in the above American figures after July, 1905. It also should be borne in mind that the excavations have now attained a considerably greater depth than in 1897.

Section	Output in Yards	Cents per Yard
Culebra Cut in 1896, Jan. 1 to Dec. 31	478,261	48.6
Culebra Cut in 1897, Jan. 1 to June 30	292,317	45.4
Emperador Cut in 1896, Jan. 1 to Dec. 31	257,555	71.5
Emperador Cut in 1897, Jan. 1 to June 30	285,532	62.2

From the outset Mr. Wallace had shown a strong bias in favor of reviving the old project of M. de Lesseps for a sea level canal, although after the disastrous failure of 1889 it had been rejected by every French and American commission that had technically studied the subject. In November, 1904, at a hearing before a Congressional Committee held in Colon harbor, he made suggestive references to it; and finally in his report of February 1, 1905, he an-



Culebra Cut at Kilometre 54.25, in 1895

Culebra Cut at Kilometre 54,25, in 1899

nounced, upon the basis of the above experimental excavations at the Culebra, or rather those of them terminating before the date of his report: "The Chief Engineer feels warranted in recommending 50 cents per cubic yard as the unit price for this central section for estimating purposes. He is also satisfied that each excavating unit, after the necessary track systems are properly installed and the organization perfected, will produce an average output of 1000 cubic yards per machine per single daily shift, and that this average can be continuously maintained, yielding an output of 300,000 yards per annum per machine . . . It would not be wise to make calculations on an excess of 100 machines continuously at work. This would yield an output of 30,000,000 yards per annum. On the sea level plan there are, in round numbers 186,000,000 cubic yards of material in the Culebra division, which would require on the above basis six years to excavate. Allowing two years for preparation and two years in addition for contingencies and unforeseen delays, it would seem evident that it would be possible to complete the canal or at least open it for use in ten years, certainly in twelve."

The engineering committee of the Commission, at a meeting held on the Isthmus in February, 1905, at which Messrs. Burr, Parsons and Davis were present, having this report before it, recommended the adoption of a sea level plan for the canal, with a bottom width of 150 feet, and a minimum depth of water of 35 feet, and with twin tidal locks at Miraflores whose usable dimensions should be 1000 feet long and 100 feet wide; the estimated cost being $230,500,000. The plan included a dam at Gamboa built to a crest height of about 200 feet. It was recommended that this dam be undertaken at once and completed as soon as practicable. The plan would "probably require a masonry core, with a large mass of earth and rock fill on either side of it, from the waste excavation of the summit cut . . . The necessary rates of the outflow from the lake during flood periods may be obtained by means of large pipes and gates built into the dam itself, together with a waste weir at the same point, or by means of a tunnel about 3.4 miles long through the dividing ridge between the Chagres and Gatuncillo watersheds, or by both." This report of the committee was laid before the Commission at its 80th meeting, on February 23, 1905. It was considered at the 84th and 86th meetings, when it was referred to the Committee on Engineering Plans for consideration and comment. No further action appears to have been taken thereon.

It appearing in the autumn of 1904 that the people of the Republic of Panama were alarmed at some of the legislation relative to the postal service and tariff duties in the Zone, which they feared would reduce their revenue and affect business at Panama by imposing United States duties at the Zone port of Ancon (La Boca), the President on October 18 requested the Secretary of War to visit the Isthmus and hold a conference with the governmental authorities of the Republic. This mission was successfully accomplished, resulting in the issue by Secretary Taft of executive orders which regulated the matters in question upon a basis satisfactory to all parties concerned.

Reorganization of the Commission

An order of the President dated April 1, 1905, announced in its first paragraph: "The practical result of the operations of the Isthmian Canal Commission appointed and acting under previous executive orders has not been satisfactory, and requires a change in the personnel of the Commission and in the instructions for its guidance."

The new instructions may be briefly summed up as follows:

The Commission to hold quarterly stated sessions upon the Isthmus continuing as long as public business may require, and also special sessions at the call of the chairman; four members to constitute a quorum.

An executive committee of not less than three members, to represent the Commission during the intervals between the stated sessions, to hold regular meetings at the office of the Governor at 10 A.M. on each Monday and Wednesday, a majority of the members constituting a quorum. Minutes of every transaction to be kept and transmitted to the Secretary of War and to the Commission.

Under the supervision and direction of the Secretary of War, and subject to the approval of the President, the Commission to be charged with adopting plans for the construction and maintenance of the canal; with the purchase and delivery of supplies and plant; with the employment of officers, employees and laborers, including the fixing of their compensation; with the commercial operation of the Panama Railroad and its steamship lines; with the utilization of the railroad for constructing the canal; with the making of contracts for the constructions and excavations, and with all other matters incident to the building of a waterway across the Isthmus.

The head of the first department (the chairman of the Commission) to have direct and immediate charge of the fiscal affairs; of the purchase and delivery of materials and supplies; of accounts, bookkeeping and audits; of commercial operations of the Panama Railroad and its steamship lines, in the United States; of the general concerns of the Commission, and of such other duties as may be placed on him by the Secretary of War under whose supervision and direction he shall act.

The head of the second department (the Governor of the Zone) to continue to perform the duties heretofore prescribed, including the administration and enforcement of law; all matters of sanitation within the Zone, and in the cities of Panama and Colon and in the harbors so far as now authorized; the custody of all sanitary supplies, and such sanitary constructions as may be assigned by the Commission; and such other duties as may be devolved on him by the Secretary of War. He shall reside on the Isthmus.

The head of the third department (the Chief Engineer) to have full charge on the Isthmus of actual work of construction; the custody of all supplies and plant; the practical operation of the Railroad in view to its utilization in construction. He shall reside on the Isthmus.

Officers and employees to be appointed, and their salaries fixed, by the head of the department in which they are engaged, the compensation being subject to the approval of the Commission or executive committee. Laborers hired outside the Isthmus to be engaged by the chairman subject to approval by the executive committee; upon the Isthmus this to be done by the Chief Engineer subject to approval by the executive committee.

Contracts for supplies or construction involving an expenditure exceeding $10,000 to be made only after due public advertisement, and to be awarded to the lowest responsible bidder, except in case of emergency, when, with the approval of the Secretary of War, advertising may be dispensed with. Contracts involving more than $1000 or less than $10,000 should be based on competitive bids secured by invitation or advertisement whenever practicable.

The reorganized Commission to assemble in Washington for the general purpose of reorganization and for the special purpose of fixing the number and character of officers and employees to serve in Washington. A complete system of accounts to be maintained on the Isthmus and duplicated in Washington, so that the amount of work done, its cost, the amount of money available, the amount expended, and the general financial condition of the enterprise may at any time be reported.

The executive officers of the Commission to make duplicate reports upon the operation of their respective departments to the Secretary of War and to the chairman of the Commission, as often as may be required; and the Secretary to make a report at least annually to the President, and oftener if required.

A board of consulting engineers having experience in works of canal construction and hydraulics will hereafter be appointed; to which will be submitted by the Commission, for its consideration and advice, the important engineering questions arising in the selection of the best plan for the construction of the canal. Its recommendation after consideration by the Commission, and with its recommendation, to be finally submitted through the Secretary of War to the President for his decision.

The membership of the Commission appointed by this order to be:

Theodore P. Shonts, Chairman.

Charles E. Magoon, Governor of the Canal Zone.

John F. Wallace, Chief Engineer.

Rear-Admiral Mordecai T. Endicott, U. S. Navy.

Brig.-Gen. Peter C. Hains, U. S. Army, retired.

Col. Oswald H. Ernst, Corps of Engineers U. S. A.

Benjamin M. Harrod.

The Commission as thus reconstituted differed fundamentally from its predecessor, in that the executive power was divided between the Chairman, the Governor of the Zone, and the Chief Engineer, the duties of the four remaining members being of a revisory or confirmatory character. It held its first meeting on April 3, 1905.

Mr. Wallace, in an interview with Secretary Taft in New York City, on June 25, 1905, tendered his resignation as Chief Engineer in charge of construction work on the Isthmus, but proposed to retain his membership on the Commission; his complete resignation was requested, and was submitted in writing on June 26. It was acted upon by the President in the following letter dated June 28.

"Sir: Your resignation as member and chief engineer of the Isthmian Canal Commission, tendered in accordance with the request of Secretary Taft, which request, under the circumstances, has my entire approval, is hereby accepted, to take effect immediately."

The vacancy of Chief Engineer was filled on July 1 by the appointment of Mr. John F. Stevens; but, as he was not made a member of the Commission or of the Executive Committee, the direct jurisdiction of the Chairman was extended over the third department. Mr. Stevens arrived on the Isthmus on July 26, 1905, and at once demonstrated his eminent fitness for the position.

The new Commission soon created a Bureau of Meteorology and River Hydraulics, for the compilation and study of the various observations which had been continued, since the French régime, but of which the results had been scattered through different branches of the Engineer Department. The order was issued on June 14, 1905, and Mr. Ricardo M. Arango was charged with this important duty. It is to the intelligent and systematic attention which he has brought to the work that are due the valuable results appearing under the several technical headings of the following chapters.

The fluviograph records at Bohio, Gamboa, and Alhajuela have been continued without intermission until January, 1906, when the latter was suspended. These vitally important records supplemented by actual gaugings, both by floats and meters, have preserved a knowledge of the hydraulic history of the Chagres since the transfer. The contouring of the valley above Gamboa and of the main affluents below Bohio has also been continued, and many new rain stations have been established. Very careful borings both with wash-rig and diamond drills have been multiplied not only at Gamboa, at Bohio and vicinity, and near Gatun, but also along the line of the canal to meet the alternative of the possible adoption of a sea-level type of canal. New routes to dumps more distant from the Culebra than those selected by the engineers of the New Company have been opened, and other similar work of a preparatory character has been actively prosecuted. The uncertainty as to the final plan of the canal rendered more definite operations injudicious.

Under date of June 24, 1905, the President issued an executive order appointing the board of consulting engineers, which finally was thus constituted:

George W. Davis, Major-General U. S. Army, retired, Chairman.

Alfred Noble, Chief Engineer East River Div. P. N. Y. and L. I. Railroad.

William Barclay Parsons, Chief Engineer New York Subway.

William H. Burr, Consulting Engineer Board of Water Supply

New York City; Prof. Civil Engineering, Columbia University; Eng. Expert of Aqueduct Commissioners, New York City.

Henry L. Abbot, Brig.-Gen. U. S. Army, retired.

Frederic P. Stearns, Chief Engr. Metropolitan Water & Sewerage Board, Boston.

Joseph Ripley, Gen. Supt. St. Marys Falls Canal.

Isham Randolph, Chief Engineer Sanitary District of Chicago.

William Henry Hunter, Mem. Inst. C. E., Chief Engr. Manchester Ship Canal; Commissioner, Upper Mersey Navigation, England.

Eugen Tincauzer, Königlich Preussischer Regierungs und Baurat, Mitglied der Regierung zu Königsberg i. Pr., Germany.

Adolphe Guérard, Inspecteur Général des Ponts et Chaussées, France.

E. Quellennec, Ingénieur en Chef des Ponts et Chaussées; Ingénieur Conseil de la Cie. du Canal de Suez, France.

J. W. Welcker, Hoofdingenieur Directeur van den Ryks Water-Staat, The Netherlands.

Captain John C. Oakes, Corps of Engineers, General Staff, U. S. Army, was detailed as Secretary of the Board.

This Board was instructed by the President to assemble at Washington, D. C., on September 1, 1905, "for the purpose of considering the various plans proposed to and by the Isthmian Canal Commission for the construction of a canal across the Isthmus of Panama between Cristobal and La Boca"; their deliberations to "continue as long as they may deem it necessary and wise, before they make their final report to the Commission"; the Commission to have the plans ready in sufficient detail to enable the Board "to consider and decide the questions presented to them"; and the Board to visit the Isthmus should they deem it necessary before making their final report. Should a difference of opinion arise, "minority reports are requested."

The Board assembled as directed; sailed from New York for the Isthmus on September 28, and arrived back on October 17, having made a careful inspection of the route of the canal, receiving detailed information from the engineers and other officials as to the latest developments. They suggested certain further examinations which were promptly made by the Commission. After a study of the ample data presented, the Board reached its final conclusions about the end of November, and the European members returned to their homes. An irreconcilable difference of opinion had developed. Eight members, including the five from Europe and the three who had formed the Engineering Committee of the late Isthmian Canal Commission, favored a sea level project somewhat upon the lines which the latter had reported in February, 1905, but with important modifications; the other five members of the Board favored a lock canal with a summit level 85 feet above mean tide, formed by a dam at Gatun,—thus in large measure substituting lake navigation for a relatively contracted waterway. When the drafting of the majority report was completed it was taken by General Davis to Europe and was there signed by the European members; meantime the minority report was drafted and signed in New York. Together with numerous appendices, maps and drawings they were presented to the Commission early in February, 1906; and on February 19, were transmitted by the President to Congress, together with his own views, those of Secretary Taft, and of the Commission, and of Chief Engineer Stevens,—all substantially indorsing the lock canal project presented by the minority of the Board of Consulting Engineers, that in general principles conforms to the recommendations of every commission of engineers which has officially studied the subject since the fiasco of M. de Lesseps.

Prior to and pending the action of Congress upon these reports the press teemed with groundless vituperation against the conduct of operations on the Isthmus, forgetful that a period of preparation must precede active prosecution in a work of this magnitude so far removed from the base of supplies. The yellow fever panic which reached its height there in June, 1905, largely contributed to starting these rumors, through interviews had with deserters and men discharged for incompetency returning to the United States.

The Senate Committee on Interoceanic Canals of which Senator Millard is chairman, acting under a resolution of the Senate adopted January 9, 1906, at once proceeded to make an exhaustive investigation of all matters relating to the Canal, the government of the Zone, and the management of the Panama Railroad Company. The printed Hearings comprise three large volumes, covering 2967 pages, with a separate reprint (988 pages) reproducing the testimony of the engineers appearing before the Committee. Finally, on May 12, a vote on the type of canal to be recommended was taken: it resulted in a tie, five Senators favoring a sea-level and five a lock canal, each being of the general type recommended by the majority or the minority of the Board of Consulting Engineers. Subsequently, by the vote of a member absent on the first ballot, the former type was given the preference; and accordingly Senator Kittredge on May 17 reported a bill providing for the construction of a sea-level canal. On May 25 this bill was made unfinished business, and was vigorously debated for several days. In the mean time the Sundry Civil Bill containing the Canal appropriation for the coming year was under consideration by the House, and after an able discussion of the plan to be adopted it was amended, on motion of Mr. Littauer on June 15, by inserting the words: "Provided, That no part of the sum herein appropriated shall be used for the construction of a canal of the so-called sea-level type." This amendment was adopted by a vote of 110 to 36. In the Senate, the bill providing for a sea-level canal was finally brought to a vote on June 21, but in a radically modified form. An amendment offered the same day by Senator Hopkins struck out all after the enacting clause and substituted: "That a lock canal be constructed across the Isthmus of Panama connecting the waters of the Atlantic and Pacific oceans, of the general type proposed by the minority of the Board of Consulting Engineers, created by order of the President dated January 24, 1905, in pursuance of an Act entitled: 'An Act to provide for the construction of a canal connecting the waters of the Atlantic and Pacific oceans' approved June 28, 1902." This radical amendment had been carried by a vote of 36 to 31 and the bill itself was then passed without a division. In the House this bill was passed also without division on June 27, and was signed by the President on June 29, thus becoming definitively the law determining the type of canal to be constructed by the United States.

During this session of Congress four other matters of importance to the work received attention.

The first was a provision originally attached to an emergency bill for continuing the construction of the Canal by appropriating $11,000,000, which passed the House early in the session, but which in the Senate was made separate legislation. It had been recommended by the Secretary of the Treasury in his annual report, with a view to obviate depreciation in the market value of canal bonds; and was to the effect that such 2 per cent. bonds issued under the Spooner Act of 1902 shall have the same rights and privileges that are accorded by law to other 2 per cent. bonds of the United States. This duly became law, and under it the Secretary of the Treasury, on July 2, 1906, offered to the public $30,000,000 of gold bonds, in denominations of $20 and upward, bearing 2 per cent. interest, and dating from August 1; these bonds to be redeemable at pleasure of the Government after ten years, and to be payable in thirty years from date, interest to be paid quarterly; bonds to be exempt from taxation of any description; bids to be submitted on or before July 20. The result was decidedly a success, the Government securing nearly 104 on the average.

The second was an amendment to the urgent deficiency bill that: "The provisions of the Act entitled 'An Act relating to the limitations of the hours of daily service of laborers and mechanics employed upon the public works of the United States and of the District of Columbia,' approved August 1, 1892, shall not apply to alien laborers employed in the construction of the Isthmian Canal within the Canal Zone." As this exemption did not include the supervision needful to utilize alien labor, it was granted in a later act, but as skilled labor was omitted, the practical effect has not been what was to be desired for rapid progress, namely the continued use of a ten-hour day, which has always been the rule on the Isthmus.

The third took the form of a joint resolution, adopted late in the session, "That purchases of material and equipment for use in the construction of the Panama Canal shall be restricted to articles of domestic production and manufacture, unless the President shall, in any case, deem the bids or tenders therefor to be extortionate or unreasonable."

The last was the provision in the annual Sundry Civil bill appropriating $25,456,575.08 to continue the construction of the canal, all to be paid from or reimbursed to the Treasury from the proceeds of the authorized bonds.

Congress having adjourned on June 30 without finally acting upon the nominations of the membership of the Isthmian Canal Commission, recess appointments became necessary. These were made at once, all the acting members being reappointed except General Ernst, whose services were needed on the International Waterways Commission of which he is Chairman. His vacancy was filled by the appointment of the Chief Engineer, Mr. Stevens, who thus now performs the duties of both offices.

Thus, after the lapse of about two years devoted largely to preparations, a stage has been reached when it is reasonable to anticipate rapid and decided progress in works of construction. The following is a summary statement of present conditions, based on a report of Chairman Shonts addressed to the Secretary of War under date of April 23, 1906, giving the results of his observations during a recent trip to the Isthmus, which was transmitted to the Senate Committee on Interoceanic Canals on May 7, 1906.

(1) Provisions for the water supply of the five important dis-

tricts have nearly reached completion, as indicated by the capacities of their reservoirs:

Panama	800,000,000 gallons
Empire	850,000,000
Gorgona	500,000,000
Colon	850,000,000
Bas Obispo, unlimited supply	from perpetual running stream.

Although the past dry season had been exceptional as compared with records for twenty-five years, it was only at Colon that the reserve was occasioning anxiety, causing the hauling by trains into that district of 250,000 gallons daily, pending the coming of the rainfall. Water is supplied to the cities of Panama and Colon free of cost to the population.

(2) The health conditions under the administration of Governor Magoon are most satisfactory. Although the monthly pay rolls now show from 22,000 to 23,000 employees, with a daily effective force of about 16,000 or 17,000, Colonel Gorgas reports the rate of sickness at only 20 per thousand. There has been no authentic case of yellow fever since last November, and mosquitoes are becoming rare. The question of quarantine is receiving earnest attention, as danger is now feared only from outside.

(3) The building department has not only provided ample quarters for the existing force but has a reserve sufficient to accommodate 3,000 additional laborers. For American employees, nine large mess houses or hotels are maintained at different points on the line, where nourishing meals are served at a cost of 30 cents each; and other similar buildings are under construction. Refrigerator cars are in operation on the Panama Railroad, and a temporary cold-storage plant is in successful operation at Colon. So far as common laborers are concerned, although wholesome and nourishing food is offered at a cost of 10 cents per meal, they do not avail themselves of the privilege except in small numbers. Efforts are making to improve these conditions. Uncooked food is now obtainable at reasonable prices by both classes of employees.

(4) Chief Engineer Stevens is prosecuting with great vigor measures to prepare the terminal, yard, and track facilities needful for handling the vast amount of supplies for canal construction, as well as for removing excavated material, and to secure the needful plant for the same. The policy of transferring the chief terminals from Colon to Cristobal, in the Canal Zone, and of concentrating work there, as well as of improving similar structures at La Boca on the Pacific side is actively in progress. Two new docks (No. 11 and No. 14) at Cristobal are essentially completed, with their cranes in position; as is also a 27-foot channel leading to them. Each dock will accommodate two ships. A new dock has been completed at La Boca, and further improvements are in progress there. The main receiving and forwarding yards at Bas Obispo and at Pedro Miguel are well under way to receive the dirt trains coming from the various levels of the Culebra Cut, there to be switched to the main line of the Panama Railroad. The double tracking of the latter is rapidly progressing, and its necessity, especially near the two yards, is illustrated by the fact that recently 148 train movements were made over one section in a single day.

(5) At the Culebra Cut advantage has been taken of the present dry season to put the works in shape for rapid progress in the approaching rainy season, and for installing the maximum number possible of steam shovels. Tracks have been laid and ballasted on each level, with a double track through the bottom of the cut; and the debris from the recent slides has been cleared away, and measures taken to prevent like occurrences in the future. During March 240,000 cubic yards of material were removed with an average of 10.7 steam shovels working, and by midsummer it is expected to have 40 of them in operation. (Nineteen were reported early in July.)

(6) The improvement in administration in the division of materials and supplies during the past six months, under the direction of Mr. Tubby, has been phenomenal. Inventories of property on

hand, improved facilities for storage, and a perfect system of registration secure at all times a definite knowledge of what is on hand, avoid risk of duplication of orders, and reduce expenses. Bills for materials received are now checked and returned for payment by the next steamer, although the receipts have been greater than ever before.

(7) The working force of the Isthmian Canal Commission on April 1st, broadly distributed through the different departments, numbered 16,881 employees. The morale and efficiency continue to improve, and this is true even of the common labor, although no high degree of efficiency can be expected in the latter until a better class is introduced.

(8) Under the administration of Governor Magoon law and order continue to be maintained to a degree that would be remarkable under any conditions, and which is especially so when the character of the population of the Zone is considered, with its vast army of 23,000 employees gathered from all parts of the world. Serious crime is almost unknown.

(9) It has been recently decided to establish on the Isthmus a local examining board, to be composed of canal officials, acting under the Civil Service Commission, for the purpose of testing the fitness for appointment to positions subject to the civil-service requirements, of such persons as may appear before it voluntarily, with the approval of the local officials. This board will also consider transfers and promotions of employees to positions coming under civil-service rules. The eligible lists resulting from these examinations are to be separate and distinct from those resulting from examinations in the United States.

(10) The old monetary agreement with four local bankers for supplying Panamanian silver, expiring by limitation on April 29th, has not been renewed. The disbursing officer has been authorized to import United States coinage and currency, when necessary, to meet obligations on the Isthmus. It is believed that there will be no

difficulty in thus meeting the major part of the pay-roll obligations.

(11) A recent conference between the authorities of the Panama Railroad and Pacific Mail has resulted in a settlement of all points of difference, and an agreement has been reached to work in harmony in the interest of the entire route. Since the middle of last December there has been no congestion of freight on the Isthmus. The steamers leaving New York every five days are promptly loaded and discharged on arrival at Colon. In order to relieve Mr. Stevens of some of the details, Mr. Bierd has been promoted to be general manager of the Panama Railroad, a merited reward for efficient service. The equipment of the road in passenger cars is to be largely increased. There are now four passenger trains daily in each direction, of from five to seven cars each, and they are often overloaded. The shares are now all owned by the United States.

(12) The duties of disbursing officer and local auditor have been consolidated, which will facilitate the payment of the enormous pay rolls. Already a gain of two days in beginning and ending has resulted.

(13) Engineer headquarters have been removed from Panama to Culebra with decided advantage. The disbursing and auditing departments will soon be moved to Empire, in the near vicinity. The headquarters of the medical department are to remain at Ancon, near Panama, and the offices of the Governor are to be transferred there from the old canal administration building in the city when the needful buildings are completed.

In fine, this official inspection by Mr. Shonts should satisfy every one that the first stage of the great work of constructing the canal —that of preparation—is drawing to a satisfactory close; and now that the plan has been authoritatively settled it is fair to expect rapid progress in the near future. It is to be hoped that those charged with the responsibility will receive hereafter the cordial support of the public, and be spared from the fire of criticism which ignorance of the conditions on the Isthmus has stimulated in the past.

One more question of primary importance has come up for decision, now that the route and plan are settled. Shall the work be done by contract or by day's labor? Although the conditions are greatly modified, previous experience on the Isthmus is not without interest in this connection. The operations of the New Company were all tentative, and were conducted with so little capital that only direct employment of labor was practicable. The old Company under M. de Lesseps tried three different methods. The work was inaugurated and continued by hired labor until 1883, when, with the advent of M. Dingler to the immediate direction on the Isthmus, the method of small contracts with renting of plant at low rates was introduced. Nearly thirty were granted. In some cases they resulted favorably, but in others serious difficulties were developed. Very frequent payments and a small army of inspectors were required. However limited a contract, it was impossible that some portions of it should not be more easy of execution than others; and when such parts had been completed there was a disposition either to throw up the remainder, or to resort to law before the Colombian courts nominally to determine disputed measurements or doubtful terms of the contract; and for such suits it was always easy to find counsel to be paid by a share of the profits. Moreover at this early period much of the excavation, distributed widely along the route, could be and was executed by hand and removed by small Decauville cars well suited to the low grade of labor available, but when more serious operations involving the employment of locomotives and excavators on a large scale was reached a change became obligatory. It was decided, although at considerably increased cost per cubic yard, to divide the work among a few large contracting companies commanding sufficient means to prosecute it rapidly and effectively. This change was made in the last months of 1885. Although some of these large contracts were fairly successful, especially those involving dredging under water, the general result was a failure, and the final collapse of the Company occurred at the end of 1888.

The conditions now presented are radically different in at least three respects. The needful funds are certain to be available no matter what system of operation be adopted. There will be no trouble from Colombian administration of justice, a change greatly to our advantage. Large public works are habitually executed by contract in the United States, and awards will be made to none but responsible parties. On the other hand, one difficult problem must be solved. Under the French administration no use was made of the tracks of the Panama Railroad as routes to the dumps; now it is proposed so to use them largely. How to accord such use to contractors without liability of interruption to the commercial business of the road is not a simple problem.

The following letter, dated August 29, 1906, addressed by the Chairman of the Isthmian Canal Commission to the Secretary of War, sets forth the conclusions of the Commission upon this subject, with the reasons therefor. The plan was approved, and proposals were invited on October 9, to be submitted not later than December 12, 1906—subsequently extended one month.

"I beg to transmit a proposed invitation for bids to complete the construction of the Isthmian Canal upon a percentage basis, including as a part thereof, for greater convenience of consideration, the terms of a contract to be entered into thereunder.

"As to the general advisability of contracting the work of completing the Canal, we know from experience that the difficulties to be overcome in the successful prosecution of any great work are in direct proportion to the magnitude and complexity of the enterprise. Furthermore, experience and observation teach that the best results in any field of human activity are accomplished by those most skilled in that particular field of human endeavor.

"The physical construction of the Panama Canal is, all things considered, the greatest task of modern times. It is in the highest degree exceptional in magnitude, complexity, and cost. In order, therefore, to most successfully, economically, and quickly finish this great work there should be associated with the Commission the best trained talents of the world in each particular department of the undertaking.

"The question may be asked, Why does not the Commission gather together experts in each branch of the work, and with them as heads create its own organizations and do the work by day's labor? If the elements of time and cost did not enter so vitally into the undertaking, the Commission might do this; but because of the unprecedented and greatly extended industrial activity of the time, and the consequent violent competition for all classes of superintendents, foremen, subcontractors, skilled mechanics, and even ordinary laborers, it would take the Commission years to secure men and build up departmental construction organizations which would equal in efficiency those now controlled by the leading contractors of the United States.

"If, therefore, the Commission, by associating with it the best trained construction men available, can receive the immediate benefit of the existing organizations which these men control, and which they have spent years in perfecting, and can by reason of their assistance complete the Canal in shorter time and for less money, is it not the part of wisdom and sound business judgment to do so?

"If the wisdom of contracting the work of completing the Canal be conceded, the question remains, What form of contract is best?

"Whether—

"(1) To divide the work into sections, and let each part to a separate firm of contractors; or,

"(2) To let the entire work to one firm or company on the basis of unit prices; or,

"(3) To let the actual work of construction to an association of contractors, each member of which will be an expert in some branch of the work, on a percentage basis.

"Before discussing the relative merits of these various forms of contract it may be well to describe the actual work to be done under the agreement.

"It is clear that under any character of contract it would be incumbent upon the Government to reserve to itself on the Isthmus the great departments of Government, Sanitation, and Engineering. With a complete staff organized for this purpose it is easy for it to assume other obligations scarcely less essential to the welfare of the work, and, indeed, almost a part of its governmental duties. The control of quarters, and of the subsistence department, so directly connected with the health and well-being of Canal employees, must be retained directly; or if the subsistence department be turned over to the Contractor it must still be subjected to a rigid supervision. In no event can the Contractor be allowed to make of this department an independent source of profit. The retention of the entire Commissary Department, needed for the supply of the Commission's own men, becomes in this connection further advisable. The elaborate construction plant which the Government has installed, and its maintenance, render likewise expedient the retention of the Department of Materials and Supplies. The Panama Railroad, with its commercial business extending to all parts of the world, can not wisely be turned over to the Contractor. With all these facilities thus retained by the Government, it becomes possible for it, with little additional expense, to supply at a very much lower cost than any Contractor could the raw materials for the Canal, the careful selection of which, uninfluenced by consideration of profits, is admittedly a matter of first importance.

"Upon general grounds of policy, and of an immediate and far-reaching economy as well, it therefore seems advisable to confine the work to be done by the contractor to actual construction. These considerations necessarily exclude the idea of contracting for a finished canal as a whole, where the material, as well as the labor and all other items entering into the cost, shall be furnished by the Contractor.

"As to the best form of contract applicable to the work of construction proper:

"The chief objection to the first proposition, viz., that of dividing the work into sections, and letting each part to a separate firm of contractors, is that there are so many perplexing elements and questions entering into this work, such as the control of labor in supply and price, repairs to and maintenance of plant and equipment, and the necessary conflicting relations of so many Contractors to the Panama Railroad, as to make the task of preventing the most serious complications between these antagonistic interests under that plan a hopeless one.

"There is also the further serious objection that even after the utmost precautions are taken, one or more of the Contractors is certain to prove unsatisfactory, to the confusion and delay of part of the work; and an undue delay to any one part of the work means a delay to the whole.

"The objection to the second alternative, viz., that of letting the work as a whole to one firm or company on a basis of unit prices, is that it would cost too much. Any contractor who successfully carries out this great work will be entitled to a fair profit, but to his estimate of cost and fair profit, he must add, if bidding on unit prices, and honestly intending to carry out his contract, a substantial increment to protect himself against unforeseen contingencies and possibly severe losses. The contract thus becomes to a great extent speculative; but while it certainly is not desired that an undertaking of so much consequence as this should be the Contractor's ruin, with a consequent disorganization of the work, neither is it desired that it become a source of enormous and unreasonable profits at the Government's expense, as would be the case if the contingencies the Contractor guarded against in his estimates did not occur.

"This brings us to the consideration of the third proposition, viz., that of letting the actual work of construction to an association of contractors on a percentage basis.

"As outlined in the accompanying papers, this plan contemplates a competition for the work between two or more groups of contractors, each group composed of contractors who have achieved a significant success in at least one of the departments of construction involved in the present undertaking and whose combined experience covers the whole task. By the terms of the invitation proposals by single individuals or firms whose experience and whose organizations must be relatively limited are therefore discouraged.

"The contractor who receives the award will be paid an agreed percentage upon the estimated reasonable cost of the actual construction work as fixed by an engineering committee of whom the contractor will name two members and the Commission three. This committee will likewise, from all available data, estimate a reasonable time for the completion of the canal; and a system of premiums and penalties to be paid to the contractor accordingly as the work is completed within or beyond such estimated cost and time is provided for. The amount of percentage to be paid the contractor fixes the basis of competition.

"This plan is not novel. It is being employed increasingly by the oldest, largest, and most successful corporations in the country. Its advantages are many:

"(1) The Government will get the benefit of the combined efforts of the best and most experienced contractors in the world, each in charge of a department in which he is a specialist and co-operating with other specialists, because all are sharers in results, to bring the whole work to the earliest and most successful conclusion.

"(2) The Government will secure the co-operation of these powerful interests in keeping full the ranks of foremen, locomotive engineers, steam-shovel men, and mechanics of all classes and with the best men of each class.

"(3) The Government will know exactly what the work costs in every part, and as it progresses, and will know it is only paying a fair and reasonable profit on same.

"(4) The plan offers every incentive for speedy and economical construction by penalizing extra time and cost and rewarding better than contract performance as to either. The Government can well afford to pay bonuses on time, as the annual interest saved to it will after five years be double the amount of bonus paid per year.

"(5) By retaining control of the work and exercising strict supervision through its engineering force the Government will protect itself against cheap or faulty construction.

"(6) The financial responsibility of the association of contractors will be beyond question, and its bond for $3,000,000 will amply protect the Government, in so far as a bond can be made a protection.

"(7) The contract will be more flexible. It will not be necessary to settle in advance all the main details of the work which could not subsequently be modified in material respects under any other form of contract save with the consent, perhaps unattainable, of the Contractor and his sureties. Wide departures from the general plan may subsequently be made without affecting the real interest of either side. Points which at the outset might otherwise be difficult, if not impossible, to adjust, may be disposed of as they arise.

"(8) Friction will be avoided. Claims and counterclaims inevitably attendant upon changes in the plans and specifications with an accompanying train of contentions, will to a great extent be eliminated.

"(9) Probable saving to the Government. No great undertaking, covering a long period of time, has ever been accomplished without the discovery, during its development, of new methods and machinery which have shortened the time and cheapened the cost of the undertaking.

American inventive genius is not dead; history will repeat itself; and the time and cost of completing the Canal as estimated will in all probability be reduced by the application of new principles which will be discovered as the work progresses. It is conceivable that the Government may receive as the fruits of the system of rewards embraced in this plan savings sufficient to offset the entire percentage required to be paid the Contractor on the estimated cost of the work.

"(10) Finally, a termination of the contract, should it become necessary, would be less disastrous to the Contractor, while an effective resumption of the work would be made easier to the Government, owing to its close relations thereto.

"In view of the foregoing considerations I strongly recommend that the inclosed invitation for bids to complete the construction of the Canal on a percentage basis be issued."

The following abstract of the conditions of the proposed contract will make known its general character.

Proposals to be expressed in terms of a percentage upon the estimated cost of the construction. This cost to be determined by an Engineering Committee of five members, three to be nominated by the Commission and two by the contractor, the Chairman to be the Chief Engineer of the Commission. Said cost not to include the means, facilities and materials to be supplied by the Commission, or interest charges, or any expense incurred by the Commission in discharging the portion of the work reserved to it, or those incurred by the contractor for organization, administration, legal, general or other expenses as defined in Article VII, or for losses or damages attributable to him or his agents, or for contingencies. A similar estimate for reasonable time for completing the canal to be made by the Committee, upon a basis of the employment of a force equal to the number that can be efficiently kept at work during legal hours.

Monthly payments to be made to the contractor, covering the actual cost during the previous month of construction work as specifically set forth in the agreement. Upon the completion and acceptance of the construction work final payment to be made, under stipulations similarly set forth covering premiums and penalties based on a comparison of the estimated and the actual cost and time.

All work to be done according to plans and specifications furnished by the Chief Engineer, such plans to be subject to changes if deemed advisable. The work of the contractor to be construction work proper, as defined by eight paragraphs in the contract.

The Commission to furnish free of cost to the contractor plant, facilities, and means as set forth in fifteen paragraphs.

The contractor to furnish and employ all labor, foremen, superintendents, clerks, general office staff, and to supply minor tools and machinery; and to make outside repairs upon equipment and machinery used by him. He will take over all employees on the Isthmus upon the pay rolls of the Commission, except such as may be reserved for its own use. Those on the "gold list" not to be discharged, or their salaries reduced, except for cause approved by the Chief Engineer of the Commission. The contractor to assume all contracts for foreign or other labor that may have been entered into by the Commission. He will observe all rules issued from time to time by the Sanitary Department of the Commission, and comply with all laws of Congress or of the Canal Zone. On written notice from the Chairman or Chief Engineer he will discharge for cause any employee in his service. All work to be done in a most thorough manner and subject to the orders and directions of the Chief Engineer. To carry on construction work by night as well as by day, if required. No transfer of contract, or subcontract under it to be made except with the written consent of the Commission. He will be responsible for damages to plant or canal caused by error of judgment or negligence, but not by ordinary wear and tear.

Proposals may be submitted by any association of contractors legally competent, and having a clear capital of five million dollars. The successful bidder to give an approved bond for two million dollars for faithful execution of the contract.

There were four offers at 28 per cent., 12.50 per cent., 7.19 per cent., and 6.75 per cent. on estimated cost; but no award was made immediately, the matter being held under advisement.

In November Mr. Roosevelt, who has taken a deep interest in the success of the canal, made a personal inspection of the works on the Isthmus, thus giving the first example in the history of the country of a visit to a foreign land during a Presidential term of office. While there, he issued an important order, dated November 17, 1906.

The Executive Committee was abolished. Seven Departments were created, under direction of the Chairman. These, with their present incumbents, were: Chief Engineer, John F. Stevens; General Counsel, Richard Reid Rogers; Chief Sanitary Officer, Colonel William C. Gorgas; General Purchasing Officer, David W. Ross; General Auditor, E. S. Benson; General Disbursing Officer, E. J. Williams; Manager of Labor and Quarters, Jackson Smith.

The Chairman to have general charge of all Departments, appointing their Heads subject to the approval of the Commission; and of the operation of the railroad and steamship lines.

The Chief Engineer to direct all engineering and construction work, and the canal operation of the railroad, and in the absence of the Chairman, to act for him in urgent matters.

The General Counsel to have charge of all legal matters; and of the administration of the civil government; and, through a local administrator, to exercise the authority vested in the governor.

The Chief Sanitary officer to have full charge of all sanitary matters in the Zone, the cities of Colon and Panama and the harbors.

On February 26, 1907, the President decided to award no contract at present, but to continue the work by day's labor under Major George W. Goethals, Corps of Engineers, as Chief Engineer, Mr. Stevens' resignation having been tendered and accepted. Majors David DuB. Gaillard and William L. Sibert, Corps of Engineers, will assist him, and all three will become members of the Commission. It is not the President's purpose "to disturb in any way the present organization on the Isthmus, which is very satisfactory, nor to interfere with the admirable work now being done by the present Assistant Chief Engineer, Mr. Ripley, and the various heads of departments. The work of construction is going on well."

CHAPTER III

THE RIVAL ROUTES

Careful examination of all the routes for a ship canal to cross the American Isthmus has amply justified the Commission of 1899-1901 in reporting that two of them alone are worthy of serious consideration. These are that by Panama and that by Nicaragua. For many years the former was considered as preëmpted by France, and the United States could only hope to secure the second best, which was believed to be that by Nicaragua. This latter route had been repeatedly examined, and finally, in 1898, with some misgivings on the part of those best informed in the matter, Congress had nearly decided to take decisive action and begin the work of construction. Never was there a more conspicuous illustration of the wisdom of the old adage *festina lente*. Now that the peril is passed, and in the light of the important developments made known since that date, we can calmly and without exaggeration consider what sort of a canal we were about to undertake.

The first point for consideration in judging of the merit of a projected canal is the facility of approach for large vessels. Natural harbors do not exist in Nicaragua, but this statement does not fully cover the case. On the Pacific coast one may be excavated and probably maintained at moderate cost, but on the Atlantic coast a never ending battle with the forces of nature is inevitable. Fifty years ago a good harbor existed at Greytown, and lines of steamers connected it with New York and New Orleans. Now it has become a lagoon, shut in by the advancing sand movement occasioned by winds and waves acting upon the materials transported in vast quantities by the San Carlos and Serapiqui rivers from the volcanic region where they take their rise. We have learned by experience on the South Atlantic, Gulf, and Pacific coasts of the United States what such a struggle with nature means. Costly works of improvement, annual outlay for dredging, and liability to temporary closure by violent storms such as are not infrequent in this tropical region, must be contemplated.

The general characteristics of the inland district to be traversed next demand attention. Central America has long been the home of volcanoes. Lake Nicaragua itself owes its separation from the Pacific, and its elevation to a height exceeding 100 feet, to some convulsion of a former geologic age. The earthquake of 1844 raised upon it waves which caused immense damages on the banks; and ships following the canal route must pass in the close vicinity of an active volcano, Ometepe, which had a violent eruption in 1883. We have recent and conclusive evidence as to the lack of stability of the earth crust at San José de Costa Rica, about sixty miles from the eastern locks of the projected canal, furnished by the reports of the Directors of the *Instituto Fisico-Geografico,* there established. From January 1, 1901, to April 30, 1904, a period of 40 consecutive months, these official records (although two months are lacking) show 43 slight tremors, 91 slight shocks, and 35 strong shocks, the decided movements continuing for more than 16 minutes. Similar but uninterrupted observations made at Panama for these same forty months show only 6 tremors and 4 slight shocks, the movements continuing for about 10 seconds. The delicate adjustments of the lock gates of a ship canal are liable to injuries from strong shocks, entailing delays in transit, while the more violent disturbances which have occurred in the last few years in other parts of Central America could hardly fail to close a canal for long periods. Common sense dictates that the canal should not be placed in the region of greatest danger from earthquakes to be found any where upon the continent, when a safer and better route exists elsewhere.

But there are other general characteristics of the region traversed by the Nicaragua route which show it to be ill suited to the transit of ocean shipping. Such are the strong trade winds that sweep through the gorge of the San Juan river at all seasons of the year. The difficulty in directing the ship would be further increased by the phenomenal rainfall near the Atlantic coast, where it is greater than at any other point on the American continent. The annual average is from 260 to 270 inches, and 25 feet are of record at Greytown, where there is no definite dry season; rain may be expected any day in the year. In the western or lake section the rainfall is much less, being annually about 65 inches, and here the route is favored by a well defined dry season. The safety of ship-canal navigation is largely dependent on clear vision, especially by night, and this the conditions existing near the Atlantic coast certainly do not favor. Another serious difficulty would result from the fact that ships must follow the tortuous course of the San Juan river for nearly 50 miles, and although the Isthmian Canal Commission of 1899-01 has given careful study to the subject it has been found impossible to reduce the curvature to the limit that experience on the Suez canal has shown to be demanded for easy transit. Furthermore, the channel of the river must carry to the sea all the drainage of about 12,000 square miles of territory, causing at times currents prejudicial to navigation, and complicated by eddies at the mouths of the principal tributaries, of which the Sabalos river is the most important. In fine, then, this long river route, exceeding in length the entire distance from ocean to ocean by the Panama line, must remain subject to the combined effects of strong winds, sharp curvature, and longitudinal and cross currents, to say nothing of the obscuration due to heavy rainfall. It may well be doubted whether any system of artificial lighting could render night transit safe for large ships, and without it delays and possible congestion could hardly be avoided.

No little stress has been laid by the advocates of the Nicaragua route upon the advantages furnished by the great lake that forms a part of it for about 70 miles. The fact has been ignored that about 29 miles of this distance lie through an artificial channel to be excavated in soft mud, where supplementary dredging may often be required; and that about a mile and a half of the western portion must be blasted through rock. The cost of opening this part of the route has been estimated by the Isthmian Canal Commission of 1899-01 at nearly $8,000,000, and the chances of touching bottom when the ships are subject to the strong winds and waves that prevail on the lake may well be considered.

But it remains to refer to what from an engineering point of view would be perhaps the most serious objection to the Nicaragua route if completed and opened to traffic. This would be the risk of longer or shorter interruptions liable to result from the complicated system of water supply in seasons of drought of long duration; and the lake lies in a district where they are far from uncommon. It has been claimed that a vast lake about 3,000 square miles in extent must furnish an ideal source of supply, but the matter will bear a little examination. By the dam on the lower San Juan river the channel of the present stream would be transformed into an arm of the lake, maintained sensibly at the same level, and through this arm all shipping must pass, the depth of water depending wholly on the stand of the lake. This stand is now subject to a natural oscillation of about 13 feet. Under the projected conditions the entire outflow must pass over the dam at a distance of about 50 miles from the main lake, and if the level is allowed to rise above the present high-water stand, valuable lands under cultivation on the west shore of the lake would be flooded and claims for damages would result. On the other hand, the bed of the river is crossed by many ledges of rock, and the cost of excavation fixes a limit to the depth economically practicable. The matter was ably discussed by the Isthmian Canal Commission of 1899-01, and the conclusion was reached that the natural oscillation of 13 feet must be reduced to rather less than 7 feet. The level of the lake must be held approximately between 111 feet and 104 feet above tide, and the bed of the present river must be excavated sufficiently to afford a sailing depth of 35 feet at all times. But the records establish that years of high lake and years of low lake follow in no regular succession. As it is impossible to provide a reserve sufficient to control the level of an immense body of water 3,000 square miles in extent, the regulation of this vital element must be left to the foresight and good judgment of the operator controlling the outflow at the dam. The uncertainties under which he would labor are clearly set forth in the report of the Isthmian Canal Commission.

"The preceding results obviously can not be considered finally conclusive as to what may happen in regulating the lake in the manner desired, for the reason that a larger monthly rainfall than that corresponding to 16.7 inches at Grenada may occur in October of any year, or in any other month following preceding rainy months which have left the ground in a saturated condition. Concurrent rainfall and lake-stage records are not sufficiently extended to afford a demonstrative treatment of this part of the question."

Carelessness, or bad judgment on the part of the operator at the dam, or an abnormal season, might therefore involve the stoppage of traffic for an indefinite period. A really desirable canal should be subject to no such contingency.

In reference to the technical difficulties of construction little need be said, now that the work is no longer contemplated. Although the dam on the San Juan river has been considered "feasible" by good engineers it is certain that no such construction has ever been executed. To sink a long, continuous, and water-tight row of pneumatic caissons upon the rock bottom, at the extreme practicable depth of operation, below the bed of a river that cannot be diverted, and where the work is liable to be deeply submerged by floods, whether in the San Juan or the San Carlos, is certainly neither an easy nor a safe operation. But the dam is not the only technical conundrum. The deep excavation at the Culebra, on the Panama route, has been so much discussed that the difficulties of similar work in Nicaragua have not attracted the attention which they de-serve. The Senate Committee on Interoceanic Canals was informed by one of the members of the Isthmian Canal Commission of 1899-01: "The cut at Tambercito is in hard rock, and while it is deep there is no trouble about that. The conditions are favorable; but at these other two places the conditions are not favorable, and we find that underneath the rock there is a layer of clay. In one place we go through rock twice in our borings and then strike clay in the prism of the canal. That is not an ideal condition of affairs. The Culebra cut is a long one, but the material there is thoroughly understood now." . . . "I would rather take the Culebra." Another member laid stress upon difficulties of another character: "I think that swampy country between Greytown and the San Juan river is going to be a very difficult country to work in. It is practically a continuous swamp." . . . . "It is about 40 miles, practically." . . . "It is a swamp throughout. There are no roads in it. You cannot make any roads except by hauling in material to make them. There have never been any, and there is a good deal of timber in that swamp. How much of it is below water I do not know. I do not think we have any idea; but there is, in my mind, a very uncertain element as to how much timber you will find to interfere with your dredges while working in that swamp." . . . . "A good deal of it is ooze—soft. It is perfectly natural that there should be a swamp in a country of such excessive rainfall."

It should be carefully borne in mind that the language of the law under which the Isthmian Canal Commission of 1899-01 was required to act called for information respecting "the most feasible and practicable route" without demanding an opinion as to the absolute merits of the canal when opened to traffic. The Report nowhere states that a Nicaragua canal completed according to the project would furnish a fully satisfactory transit route, capable of competing on favorable terms with that by Suez. The fact that they estimated the annual cost of operation and maintenance at $1,300,000 more than at Panama sufficiently indicates that they appreciated its inherent defects in rejecting it.

It remains to apply this test of practical utility to our contemplated canal by way of Panama. In the important element of natural harbors the route has met all the requirements of commerce during the four centuries since its discovery. On the Pacific, when the canal reaches deep water, no works of harbor improvement will ever be required. On the Atlantic, the natural depth now meets the needs of ordinary commercial steamers, and when more is required it may be secured, without fear of serious deterioration, since there are no river-borne sands to be combated.

The merits of the inland route are equally conspicuous. The distance is only about 46 miles from ocean to ocean, or only one-quarter as long as that by Nicaragua, and the summit level may be fixed, as was projected by the New Company, at about 65 feet, or a little more than half that at Nicaragua. The route is swept by no strong winds; the curvature is exceptionally favorable as compared with existing ship canals; the annual rainfall ranges from about 140 inches on the Atlantic coast, to about 93 inches in the interior and about 60 near the shores of the Pacific, with a well defined dry season of fully three months: and with judicious regulation of the Chagres river there will never be objectionable currents in any part of the route. The transit from ocean to ocean may be made in a single day without encroaching upon the night, but night passages can be made easy and safe by a system of electric lighting supplied by water power at dams on the Chagres. The floods of the river may be readily controlled, and ample provision to meet the low-water requirements of the canal may easily be made. In a word, an excellent canal well suited to the needs of navigation may be constructed; there are no technical difficulties that will not yield to the ordinary resources of modern engineering, if judicious measures are adopted in preparing the final plans. It is true that locks will be required to reach the summit level and to descend, and one to overcome the large tidal oscillation on the Pacific coast; but experience on our St. Mary's Falls Ship Canal has demonstrated that they will entail no serious difficulties in navigation. It has been claimed that they may be avoided by constructing a sea-level canal; but, as will be explained in Chapter VII, the regulation of the Chagres river under these conditions will introduce features far more objectionable than modern locks.

It may be interesting to refer to the three objections which have been raised by the advocates of the Nicaragua route. These are the greater distance from our Atlantic and Gulf ports to San Francisco; the obstacle to the passage of sailing ships caused by uncertain winds in the Gulf of Panama; and lastly the health question.

As to the first, the objection is apparent rather than real, since the time lost on the longer sea route will be fully compensated by the gain in time required to traverse the canal, to say nothing of the saving in cost due to lower insurance rates, which will probably be only about one-fourth as much by Nicaragua. A somewhat full discussion of this matter seems to be desirable.

The first element to consider is the actual distance. The following figures have been stated on the authority of Commander Todd, of the Hydrographic Bureau of the Navy Department, the unit being the statute mile: New York to Colon, 2,281 miles; New York to Greytown, 2,372 miles; New Orleans to Colon, 1,589 miles; New Orleans to Greytown, 1,448 miles; San Francisco to Panama, 3,777 miles; San Francisco to Brito, 3,109 miles; New York to Honolulu via Panama Canal (47 miles), 7,699 miles; New York to Honolulu via Nicaragua Canal (190 miles) 7,438 miles.

From these data it appears that the gain to a steamer in a voyage from New York to San Francisco via Nicaragua would be 434 miles; from New Orleans to San Francisco, 666 miles; and from New York to Honolulu, 261 miles. Assuming an average sea speed of 10 knots (11.5 statute miles), these gains in time will be 37.7 hours, 57.9 hours, and 22.7 hours respectively. It remains to inquire how much of this seeming advantage will be offset by longer delays in traversing a canal via Nicaragua than one via Panama.

Such delays result from lockages, and from difficulties in maintaining full speed arising from curvature, strong winds, and local currents, if such exist on the route.

In the matter of dimensions of cross section both of the earlier projects conformed to traffic requirements, and were in close accord. Since then the law of Congress requires a large increase, but as no corresponding study of the Nicaragua route has since been made, a fair comparison of relative times of transit can best be based on the earlier plans.

The delays to be caused by lockages in the two canals raise the question of the total height to be overcome. For the Nicaragua route nature has fixed this at the level of the lake above mean tide, or about 107 feet. For Panama, it is a matter of choice, to be determined within the limits of economical excavation by the parties in interest. The New Panama Canal Company adopted 63 feet as the most desirable solution of the problem.

Delays from lockages result from two causes: (1) loss of time consumed in actually raising and lowering the ship, and (2) loss of time in the needful preparations for so doing. The former admits of exact estimate, based on experiments at our great lock Poe at Sault Ste. Marie, and confirmed by experience there and on the Manchester Ship Canal. The limit of speed in raising and lowering found to be safe is two and a half feet per minute. This calls for 86 minutes for overcoming the ascents and descents on the Nicaragua route, and 50 minutes for those via Panama. The delays in the needful preparations depend on the number and adjustment of the locks. Careful observation of the passage of great ships through the Manchester Ship Canal has furnished the following figures, including the slackening of speed in approaching the lock, delays in entering and making fast, time spent in manoeuvering the gates, delays in unlashing and leaving the lock, and time lost in regaining full speed. For each passage of a single lock these delays aggregate 21 minutes; and for two locks in flights, 30 minutes. On the Panama route the project of the New Company called for five locks, four of them disposed in flights of two. On the Nicaragua route the Commission of 1899-1901 proposed 8 single locks. These data give the following as the total loss of time in lockages in traversing the two canals: via Nicaragua, 4 hours and 14 minutes; via Panama, 2 hours and 11 minutes: gain for Panama, 2 hours and 3 minutes.

The speed which can be maintained in traversing the water-way will be governed by the dimensions of cross section, the curvature at changes of direction, the force and direction of the prevailing winds, and the currents when any are to be encountered. Experience on existing ship canals has also shown that a limit is imperative to protect the banks from erosion. This limit is generally fixed at 6 knots (6.7 miles) per hour. Another important element in determining the practical rate of transit is the length of the levels between the locks; for if short a high speed cannot be attained in traversing them. The routes will now be compared as to these elements.

On the Panama route the minimum radius of curvature is 1,860 yards, and only one per cent. of the entire distance between oceans approaches this limit. The ruling radii are 3,281 and 2,734 yards, and 42 per cent. of the route lies between these limits; 57 per cent. follows straight lines. This matter of curvature is of immense practical importance. The Suez Company has been compelled, since the canal was opened to traffic, to increase its radius from a minimum of 700 metres to a minimum of 1,800 metres (736 yards to 1,968 yards), to secure the requisite speed of transit. On the Nicaragua project of the Isthmian Commission of 1899-01 there are, on the 113 miles of canal and canalized river, 56 curves aggregating 2,340 degrees (six and a half complete circles) with a minimum radius of 1,348 yards, and 27 miles with a radius less than experience on the Suez canal has shown to be needful for rapid transit. There are also on the 70.51 miles of lake section about 30 miles of contracted channel where full speed cannot be maintained.

In conducting a ship through a canal or narrow river, where currents are to be overcome, or where strong winds are to be encountered, either blowing across the route or acting from the rear to force her from her course in passing curves, the difficulties and risks of navigation are vastly increased. In this respect there need be no difficulty on the Panama route. In Nicaragua ships must navigate for 50 miles the crooked San Juan river, which must carry the greater part of the lake drainage, and which traverses a gorge that Admiral Walker states is swept by strong trade winds during the greater part of the year.

As to length between locks on the Panama route, the project of the New Company has only one level (1.3 miles) less than 15 miles in length. On the project of the Nicaragua canal, on the 113 miles of canal and canalized river, half of the ten sections into which it is cut by the eight locks are less than three miles in length, which defect must likewise greatly reduce the speed of transit.

In view of these facts, it would appear reasonable to accord an average rate of transit to the Panama route equal to that authorized by existing canal regulations (6.7 miles per hour), especially as for some miles in Lake Bohio it can be largely exceeded. The Nicaragua route is manifestly subject to unusual difficulties. On the Suez Canal, in 1898, the average rate of speed was only 5.5 miles per hour, and this with curves of nearly double the radius of those projected for Nicaragua, and with no currents to cause delays. It would seem a very liberal estimate to accord an average speed of 5 miles per hour, allowing full sea speed (11.5 miles) in the 40 miles of deep lake.

Adopting these figures, we find for the relative times of transit by the two canals the following figures. That they are not extravagant will appear from a comparison with the estimates given on page 86 of the Report of the Board of Consulting Engineers, for the adopted Panama Canal lock project, based on a quite different mode of calculation; namely, that thirty ordinary commercial ships could traverse the canal in periods varying from 10 hours to 11.1 hours according to their size.

	Hours	Min.
By Panama, 46 miles at 6.7 miles per hour	6	52
Loss in lockages	2	11
Add 20 per cent. for contingencies	1	48
	—	—
Time of transit	10	51

	Hours	Min.
By Nicaragua, 143 miles at 5 miles per hour	28	36
Forty miles at 11.5 miles per hour	3	28
Loss in lockages	4	14
Add 20 per cent. for contingencies	9	4
	—	—
Time of transit	45	22

These figures, allowing full speed by night, show that a steamer crossing the Isthmus from ocean to ocean will require 34 hours more time if going by way of Nicaragua than if going by way of Panama. This practically offsets the seeming advantage of Nicaragua, given above, due to shorter ocean routes. But it is further to be remembered that the figures are based on the assumption that night transits can be made with equal facility as by day. For Nicaragua this is far from true; indeed, it may well be doubted whether night transits are practicable, except in the deep lake section. If not, Panama is the shorter route, measured in time, even between New Orleans and San Francisco.

As to the second objection raised by the advocates of the Nicaragua route, the uncertain winds in the Gulf of Panama, it has been shown in Chapter I that this difficulty is discounted by practical men engaged in navigating sailing ships. Towage would be required throughout the entire extent of the Nicaragua route, and the same distance (183 miles) at Panama would carry them nearly or quite to a point where winds might be expected. It is true that the winds in the Gulf of Panama are uncertain, but sailing ships have used the route for hundreds of years, finding it to be the best for trans-shipment of their cargoes across the Isthmus.

In the matter of health the route by Panama enjoys an unenviable notoriety, but it must not be forgotten that the record has been largely aggravated by the disturbance of the surface soil in the construction of the railroad and the canal. As the excavations have now passed through this layer, and have reached the much less dangerous soil below, a marked improvement may be expected, especially when the requirements of modern sanitary science are rigidly observed. In fact, the actual experience of the New Panama Canal Company, as well as our own to date, more than justifies this expectation. The apparent superiority of the conditions in Nicaragua is probably due in no small degree to the absence of population between the lake and the Atlantic coast. This question at Panama will be further considered in the next chapter.

In fine, now that the problem has been thoroughly studied, and that the facts are known, and that fortune has enabled us to secure the better route, we have good reason to rejoice that hasty action was delayed, and that no mistake has been made in the selection.

CHAPTER IV

PHYSICAL CONDITIONS EXISTING ON THE ISTHMUS

Among the most important natural elements affecting the construction of the canal are the topography, geology, and climate of the region to be traversed, and the resulting health conditions. They will be considered in turn.

TOPOGRAPHY OF THE ISTHMUS

Nothing like a mountain chain, properly so called, is encountered on the line of the canal. The region exhibits a chaotic aggregation of short crests and isolated hills, locally denominated "*cerros*," which are usually conical or rounded in form and are seemingly disposed without order on orientation. If viewed from a distance there is an apparent tendency toward a grouping parallel to the coasts, but when the central district is penetrated one encounters disconnected plains bordered by cerros, and forming the sources or enlargements of the valleys of the water courses. Many of these cerros are of volcanic origin, which at first suggests the idea that the terrain is formed of volcanic peaks disposed around ancient craters; but as the same formation extends into portions clearly made up of sedimentary deposits it is apparent that extensive denudation has been the true cause of their origin. It is the action of rainfall and winds that has worn down the surface, and as the eruptions are of ancient date this must have been the work of long ages. The central divide is marked by a series of low serrated crests, nearly continuous, rising from 500 to 1,500 feet above tide, but near Panama this line is broken by a depression which on the canal line did not originally exceed about 345 feet. This was the extreme height at the deep cut of the Culebra which does not exceed about three-quarters of a mile in length. The total length to be excavated between the waters of the Chagres on the north and the waters of the Rio Grande on the south, including both the Emperador and the Culebra cuts, is only about seven miles; and many millions of cubic yards had been taken out when the work was turned over to the United States.

Following the line of the canal from the Atlantic to the Pacific coasts the local topography may be indicated in few words. From Colon to Gatun, where the route reaches the Chagres river, a distance of about five and a half miles, the line traverses an alluvial plain bordered by the hills of the Mindi and Quebrancha ranges, of which the summits rise about 200 feet above tide, with low foot hills about 50 feet in height. Thence to Bohio, a distance of about nine miles, the route follows the valley of the Chagres, bordered on the east by the Tiger Hill and the Lion Hill crests of similar character. At Bohio the valley sharply contracts, presenting a favorable site for locks, and then opens out into the plain of Tavernilla, which gradually rises and forms a sort of glacis to the continental divide. This district should be transformed into a lake, furnishing a route for shipping as far as Obispo, distant about 13 miles from Bohio. It should be noted, however, that after passing San Pablo, about seven miles from Bohio, the bordering hills contract, thus forming a narrow arm of the lake through which the waters of the Chagres must enter it. Here objectionable currents may be feared in floods, and even in the frequent freshets, unless provisions be made to regulate the flow by an upper lake at Alhajuela. At Obispo the continental divide above described is encountered, terminating at the end of the Culebra cut (7 miles). Thence the route follows down the valley of the Rio Grande, with a general slope about three times as great as that in the valley of the Chagres, to the wharves at La Boca, a distance of about 8 miles; excellent locations for locks to descend from Lake Bohio and to overcome the tidal oscillation of the Pacific (16.4 to 20.9 feet) are found at Pedro Miguel and Miraflores. It is fortunate for the canal that the tidal oscillation on the Atlantic coast only ranges from 0.6 feet to 2.1 feet, thus calling for no provisions for regulation. Even if a tide level canal had been found expedient, a lock near the Pacific coast would have been necessary. From La Boca to the anchorage for shipping at Isle Naos, a distance of about 3 miles, the canal has been excavated in the Bay of Panama. Thus the total distance from ocean to ocean is about 46 miles, traversing a district largely covered with a dense tropical vegetation and unbroken by any well defined mountain chain.

It remains to consider the topography of the region traversed by the Chagres before attaining the line of the canal. The slope of the terrain rapidly rises from Gamboa to Alhajuela, a distance of about 11 miles by the course of the stream. The latter is bordered at short distances by sharply defined hills covered by forests and separated by jungles through which it is difficult to force a passage even on foot. Above Alhajuela the hills close in upon the river, and its several branches constitute a network of gorges extending to the Sierra de San Blas, where they take their rise. This Sierra forms the divide between the Chagres and the numerous streams flowing south to the Bay of Panama. An old trail connects the city of Panama with Porto Bello on the Atlantic coast, but it is only practicable during the dry season. Except a few settlements below Alhajuela, of which the most important is Cruces where immigrants to California left the Chagres to take mules for Panama, in the days before the railroad, the entire region is a tropical wilderness, little explored but offering great attractions to lovers of wild natural scenery. Further details are given in the next chapter.

Geology of the Isthmus

As the writer makes no pretension to an expert knowledge of geology it is proper to state that the following views are only a brief summary based upon the report of the special Commission which, under the provisions of the "*statuts*" of the New Panama Canal Company, visited the Isthmus in 1898. Two of the members were experts in this branch of science, one of them (M. Marcel Bertrand) being a member of the Institute of France and Professor of Geology at the National Higher School of Mines at Paris, and the other (M. Philippe Zürcher), being Chief Engineer in the Corps of Bridges and Routes of Communication of France. In a geological report appended to the General Report of the Commission these gentlemen discuss the geology of the Isthmus at some length. Among the authorities quoted is Mr. Robert T. Hill:[1] but they add that an examination of a much larger number of samples of borings on the line of the canal than were available to him, has led them to form a different opinion as to the age of the eruptive rocks.

A vertical cross section of the Isthmus on the line of the canal presents the appearance of a very flat anticlinal arch of which the central and most ancient portion, known locally as the rock of Gamboa, lies at or near the surface between the 15th and 32d mile posts from Colon (between Bohio and Emperador). This rock is volcanic in origin, consisting of massive overflows or of brechias and conglomerates cemented by eruptive material of like character. The geological age is certainly Oligocene, and probably Tongrian. North and south of these limits this formation drops rapidly below later tertiary strata. The plains of Tavernilla, between Bohio and San Pablo, exhibit above the rock of Gamboa modern and ancient alluvions, the latter partially underlaid by trachytic tuff of lower Miocene tertiary. These alluvions appear again between Mamei and Gorgona.

On the Pacific slope of the anticlinal arch between Las Cascadas and La Boca the rock of Gamboa is overlain, first by Aquitanian, and then at Cerro Culebra and thence to Paraiso, by trachytes of the

[1] The Geological History of the Isthmus of Panama and Portions of Costa Rica. (Bulletin of the Museum of Comparative Zoölogy at Harvard College, Vol. XXVIII, No. 5.)

Native Village, Cruces

lower Miocene period, capped at the Cerro by andesites of the upper Miocene period. Since this is the locality where the greatest excavation is required it is fortunate that a much softer variety of rock is encountered than elsewhere on the anticlinal arch. Indeed, it is estimated that only about one-tenth of the heavy excavation lies in the hard volcanic material known as the rock of Gamboa. The Aquitanian formation on the Pacific slope is composed of argillaceous ligniferous schist of marine origin, with intercalations of tuff and andesite veins, on which rest lower Miocene strata of calcareous sandstone and marine trachytes, traversed by intrusive dykes of andesite.

On the Atlantic slope of the anticlinal arch the overlying strata of Aquitanian origin are represented by the sandstone of Vamos Vamos and limestone of Peña Blanca, occasionally covered by ancient and modern alluvions; but between Gatun and Colon strata of lower Miocene make their appearance resting upon it. Such are the mollasse of Gatun and the clays of Mindi.

One of the most conspicuous and widely distributed formations of the Isthmus has no well defined geological age. This is represented by a peculiar strata of soft, red clay which had much to do with the early sliding at the Culebra, and especially at the Cucaracha. These clays are the product of gradual surface decomposition under the influence of the tropical climate, and they naturally exhibit different stages of progress, the final form presenting the appearance of ferruginous unstratified solidified mud. Indeed they might be mistaken for sedimentary deposits constituting a special dislocated formation; and this the more that intercalations of brechias sometimes appear between different layers. But this view would be erroneous. The red layers simply mark surface decompositions more or less advanced, which naturally terminate when lower impermeable clay strata have been attained. Such soft, red clay strata were often found at the levels where caving occurred in the cuts, and the sliding was usually assisted by abundant infiltrations which transformed the red clay into a lubricator to favor the movement, when the slope of the underlying strata was turned toward the excavation. It should, however, be remarked that a well defined lower limit of deterioration is theoretical rather than real, partial connection between solid strata often remaining. Such sliding was usually confined to short distances, and experience proved that it could be controlled by ordinary engineering methods; but where such lubricating strata are encountered they should receive special attention.

Another noteworthy fact in regard to the material through which cuts are to be made should not be overlooked. The beds of comparatively impervious clay do not entirely prevent the circulation of water in the lower layers, and this may give rise to a phenomenon, quite unusual, which is shown by small specimens. Rocks apparently solid and compact disintegrate when immersed for a few moments in water and submitted to light pressure even of the fingers. This may occur even with some eruptive specimens. Microscopic examination explains the cause. Such specimens when cut thin in oil are found to be traversed by argillaceous filaments which feebly depolarize light, and which form with crystalline residues the body of the rock. These filaments appear to be the product of decomposition, although difficult to distinguish from true argillaceous deposits shown in other samples. In the eruptive rocks it is the vitreous particles that seem to have undergone this decomposition. Whatever be the chemical cause, the fact of disintegration is certain. Rocks apparently solid and freshly taken from deep shafts sometimes exhibit unstable cohesion, separating like marl or granulating like sand. It might appear that this phenomenon must cause unfavorable conditions in the cuts, but it is to be borne in mind that experience has demonstrated that deep excavations left exposed for years to the weather have stood perfectly without revetment. It would seem that in mass the material is more stable than in small fragments, and that the sides even of the great cut do not sensibly deteriorate. Indeed, it appears that the steeper the slope the better does it stand, perhaps because more massive and less exposed to wash in heavy rains. Substantial revetment of the waterway, however, may perhaps be required, as well as careful provisions for draining the successive terraces into which the long slopes will be broken.

It remains to consider the geology of the basin of the Chagres above the point where the stream joins the canal route near Gamboa. In the bed of the river near Las Cruces appears a formation of compact limestone which perhaps represents the same Aquitanian level as at the Emperador; but in ascending the valley the entire plateau as far as Alhajuela is characterized by a compact calcareous sandstone with fossils of the upper Oligocene or Miocene age. Above Alhajuela appears stratified limestone, gray and even white at certain localities. It passes very gradually under the sandstone of the lower river. In the Sierra San Blas, where the Chagres takes its rise, granite of the tertiary period has been found, and specimens are occasionally brought down by the current, but this region is little explored.

As regards the age of the volcanic eruptions upon the Isthmus, it is difficult to fix precise limits. They traverse in veins the lower Miocene upon which their flows are superposed, and it is probable that these were the latest. Nevertheless, the important fact remains that nothing here represents the more recent volcanic series of Costa Rica, Nicaragua, and Guatemala, where the existing volcanoes are only feeble successors of the ancient vents. All observers, and especially Mr. Hill, are explicit as to this point. The fact that volcanic activity has long ceased near the Panama route is of capital importance, inasmuch as earthquake disturbances are closely associated with volcanic action. Throughout the entire region between Chiriqui and Tolima, a distance of nearly six hundred miles, there are no intermediate active volcanoes. It is true that there are occasionally moderate earthquake shocks near Panama, but they can usually be traced to more violent disturbances elsewhere, transmitted with diminishing force to considerable distances. To obtain precise figures as to these earth movements two delicate self-recording seismographs were established by the New Panama Company near Panama in September, 1900, and continuous records were kept there until the property was turned over to the United States in April, 1904. A similar series of observations was kept near San José de Costa Rica by the Government of that country, beginning in January, 1901. The results have been published monthly in the United States Monthly Weather Review, with only two months lacking (November, 1903, and March, 1904). The work was in charge of M. Enrique Pittier, the Director of the *Instituto Fisico-Geografico,* whose labors in science are widely known. The station is only about sixty miles from the locks of the projected Nicaragua Canal (eastern division), and a comparison of the two sets of records is interesting. The instruments at both stations were extremely delicate, recording movements of the earth crust too slight to be detected by the senses. Such movements are classed as "tremors" in the following table, while well defined movements are classed as "light shocks" or as "strong shocks" according to their severity. M. Pittier notes in one or two of the "light shocks" that people ran out of the houses.

These figures place in strong relief the relative stability of the regions traversed by the two projected canals. During the forty-four months there were eleven tremblings of the earth's crust at Panama, of which only four were sensible, and they were too slight to cause alarm to the inhabitants. During the thirty-eight of these months for which we have corresponding records, at San José, there were 169 earth movements, of which ninety-one were classed as light shocks and thirty-five as strong shocks. But even these figures fail to present the matter with sufficient force. The duration of the motion at Panama was insignificant, while at San José the earth continued shaking during 966 seconds, or more than sixteen minutes,

TABLE 1.—ISTHMIAN EARTHQUAKE RECORDS

Dates	At Panama				At San José de Costa Rica			
	Tremors	Light Shocks	Strong Shocks	Total	Tremors	Light Shocks	Strong Shocks	Total
1900—								
September	1	0	0	1	..	..	..	..
October	0	0	0	0	..	..	..	..
November,	0	0	0	0	..	..	..	..
December	0	0	0	0	..	..	..	..
1901—								
January	0	0	0	0	5	0	0	5
February	0	0	0	0	4	8	0	12
March	0	0	0	0	0	1	1	2
April	0	0	0	0	2	0	1	3
May	0	0	0	0	1	1	0	2
June	0	0	0	0	0	0	0	0
July	0	0	0	0	1	2	2	5
August	0	0	0	0	1	0	0	1
September	3	1	0	4	2	0	1	3
October	1	0	0	1	3	7	2	12
November	0	0	0	0	1	2	0	3
December	0	0	0	0	2	0	0	2
1902—								
January	0	0	0	0	3	5	1	9
February	0	0	0	0	0	1	0	1
March	0	0	0	0	0	1	0	1
April	1	1	0	2	1	0	1	2
May	0	0	0	0	2	0	0	2
June	0	0	0	0	0	3	1	4
July	0	0	0	0	1	6	1	8
August	0	0	0	0	1	2	3	6
September	0	0	0	0	1	3	1	5
October	0	0	0	0	0	4	0	4
November	0	0	0	0	0	3	0	3
December	0	0	0	0	5	5	4	14
1903—								
January	0	0	0	0	2	1	2	5
February	0	0	0	0	0	5	5	10
March	0	0	0	0	0	2	2	4
April	0	1	0	1	1	6	0	7
May	0	0	0	0	0	3	1	4
June	0	0	0	0	0	1	0	1
July	0	0	0	0	0	1	0	1
August	0	0	0	0	0	1	1	2
September	0	0	0	0	0	1	1	2
October	0	0	0	0	0	1	1	2
November	0	0	0	0	..	..	..	..
December	0	0	0	0	0	1	0	1
1904—								
January	0	1	0	1	2	7	3	12
February	1	0	0	1	1	6	0	7
March	0	0	0	0	..	..	..	..
April	0	0	0	0	1	1	0	2
Total	7	4	0	11	43	91	35	169

giving a monthly mean average of about half a minute during the entire period. No records of this nature have been kept for the western division of the Nicaragua route, but it is well known to contain several volcanoes, with the attendant risks. The selection of the Panama route certainly was fortunate, in this as in other respects.

Climatology of the Isthmus

The geographical position of the Isthmus of Panama is about 9° north latitude. From this position it follows that at noon the sun is in the zenith twice a year; it is on the northern side between the 13th of April and the 29th of August. Its altitude above the north horizon on the day of the summer solstice is 75° 41′ and its altitude above the south horizon at the winter solstice is 57° 24′. It transmits to the surface of the earth the maximum amount of heat on April 13 and August 29.

But the temperature of the air does not depend solely upon the quantity of heat coming from the sun; it is also necessary to consider the amount lost by radiation, and the effects of many local conditions, and these may vary according to place and from one day to another. Among these conditions the motions of the atmosphere and the quantity of aqueous vapor are general and powerful factors.

Aqueous vapor is the great regulator of temperature, as it is less permeable than dry air to the waves of energy from the sun and still less so to those that radiate from the earth. Its influence in this direction is very important on the Isthmus of Panama because here only a narrow strip of land separates two great oceans, and consequently the relative humidity is always very high. By combining high temperatures with this high humidity there results an excessive absolute amount of moisture in the atmosphere.

In regard to the general motions of the air, it is well known that by reason of the high temperature in the equatorial regions the air ascends; in consequence of this we should have constantly in the lower atmosphere north winds from the north, and south winds from the south, seeking to fill up the vacuum; but on account of the rotation of the earth from west to east, these directions become northeast and southwest. Nevertheless, there are circumstances, as we shall see further on, which modify this general law on the Isthmus of Panama. Thus, the observations made daily at Colon, during the year 1881, at 6 a.m., 1 p.m. and 9 p.m. (fig. 1), show

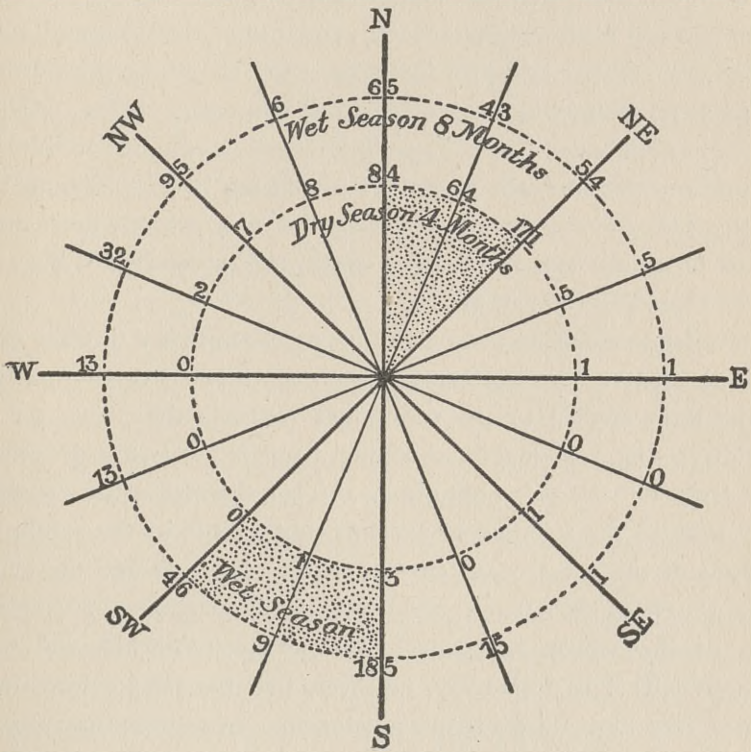


FIG. I. Wind rose at Colon for the year 1881. The figures give the total number of times each wind is recorded during the dry and wet seasons, respectively, at the three hours of daily observation. During the dry season 91 per cent. of the recorded winds are from the north and northeast. During the wet season 33 per cent. of the recorded winds are from the south and southwest.

55 per cent. of winds blowing from between northeast and northwest; 35 per cent. from between southeast and southwest; and 10 per cent. from all other directions, including 1 per cent. of calm.

Nevertheless these percentages become, during the dry season (January, February, March and April), 95 per cent. blowing from between northeast and northwest (91 per cent. from between northeast and north), 2 per cent. from between southeast and southwest, and 3 per cent. from all other directions: during the rainy season 36 per cent. blowing from between northeast and northwest, 51 per cent. from between southeast and southwest (33 per cent. from between southwest and south), and 13 per cent. from all other directions. It may be added that these wind results were confirmed in a general manner by more elaborate measurements made at Colon for eight months in 1898-99, by the United States Weather Bureau. In brief, at Colon north winds prevail during the dry season, but south winds are most common during the rainy season; thus, these winds follow the sun as it carries northward or southward the axis of the ascending layer of air.

In order to elucidate these facts one must remember that the geographic equator does not coincide with the thermal equator, which is the term applied to the curve that connects the points on all meridians where the maximum annual temperature is found (generally from 26° to 30° Centigrade). This thermal equator passes very near to the Isthmus of Panama, but a little to the south, on account of the great ocean current which carries thither the equatorial waters of the Atlantic, and consequently increases the temperature of the whole of Central America, commencing with the Isthmus. This is not to say, however, that the temperature there is ever very high, as we shall see later on. In a great measure, so far as concerns temperature, this ocean current neutralizes the effect of 9° of north latitude.

The axis of the ascending layer of air moves toward the north and retrogrades toward the south with the sun, oscillating in the course of a year, day by day, symmetrically across the thermal equator. This layer varies in thickness, from one place to another, according to the diverse local conditions, such as the configuration of the land, the duration and force of the prevailing winds, etc., but in general it is less than the distance between the extreme positions of the axis of the ascending layer.

On the whole, it follows from the above that the Isthmus of Panama is south of this entire layer for several days about the time of the summer solstice, and to the north of it for a greater number of days toward the time of the winter solstice; that is to say, that the ascending layer of warm air covers the Isthmus from the beginning of May to the end of June, and from the end of July to the beginning of December. This explains the winds observed at Colon, and many other facts concerning the climate of the region.

To sum up, the Isthmus of Panama is very near to the thermal equator, where the heat of the sun from one day to another, during the year, varies extremely little, and where it is conserved, so to speak, by a thick covering of aqueous vapor which is but slightly permeable during the day and still less so during the night. Thus, the temperature, which is determined in general by the difference between the heat received from the sun and that lost by radiation, should here have its maximum uniformity, either from day to night or from one season of the year to another.

In regard to precipitation, there are two well-marked seasons; the dry season, including the months of January, February, March, and April, and the rainy season comprising the remainder of the year. This latter season generally suffers an interruption of several days after the summer solstice, when the rains diminish. Then the ascending layer is entirely to the north of the Isthmus.

Climatic Records. Those contributed by the old Canal Company were numerous and valuable, consisting of observations on the temperature of the air at Colon, Panama, and in the interior, and on that of the water of the adjacent seas; the wind records given above; the barometric pressure at Colon; rainfall observations well distributed throughout the Isthmus; and tidal records on both coasts. The New Canal Company continued the work, introducing in 1897 the use of self-recording instruments of modern types, including thermographs, barographs, and, in 1900, delicate seismographs. The monthly records of the latter have been given above, and those of all the rest, including long continued rain records of the Panama Railroad Company, have been published in the United States Monthly Weather Review in its issues of May, 1899, March, 1903, and June, 1904. It appears needless to repeat so voluminous data here, since they may be consulted in any large library, and only such summaries will be reproduced as are needed in the discussions. Exception, however, will be made in favor of the sea temperatures and the tidal records, which have important bearings upon the climate and upon the canal problem, respectively, as will be seen further on.

The interesting observations upon the temperature of the sea were made daily at both Colon and Naos (in the Bay of Panama) for about four years. The following table exhibits the monthly means. They show marked differences between the Caribbean sea and the Gulf of Panama. The temperature of the former differs but little from the annual mean (79.3 Fah.) in May, rises gradually to a maximum in September, falls to the annual mean in December, and then rapidly to a minimum in February. The extreme oscillation is about six degrees Fah. and, as will appear later, the annual mean is about the same as that of the air. The temperature of the Bay of Panama differs but little as to dates of maxima and minima; but the annual mean is about 3 degrees Fah. less, and the extreme range is about double. It will be shown further on that these oscillations conform to the changes in direct heat received from the sun, with a retardation of about two months required to change the temperature of so large bodies of water. The Pacific Ocean especially, being here little affected by currents, is a great natural thermometer to register solar energy. The influence of the great marine current which carries the equatorial waters of the Atlantic to the Isthmus is manifest, as well as the action of the sun passing annually north and south of the zenith. The temperature of the Atlantic is generally higher than that of the Pacific by a maximum difference of about 7°, when the sun, in February, approaches the equinoctial line and the two seas are, respectively, colder than at any other season of the year. The minimum difference of 2°, in round numbers, occurs after the sun, in September, has again passed that

TABLE 2.—WATER TEMPERATURES ON THE ATLANTIC COAST IN DEGREES FAH.

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1884	......	......	80.1	......	80.6	81.7	81.9	81.7	82.6	81.9	82.2	80.8	81.5
1885	79.5	80.8	80.4	82.0	84.0	82.9	82.0	80.1	79.9	79.9	79.9	76.8	80.7
1886	75.2	74.8	75.9	76.5	75.9	75.0	78.4	78.8	78.1	77.4	76.3	76.3	76.6
1887	73.6	71.8	71.8	73.8	74.5	82.6	83.1	86.2	87.3	86.4	85.3	85.8	80.2
1888	86.4	83.5	82.9	......	......	......	......	......	......	......	......	......	......
Means	76.1	75.8	77.0	77.4	78.8	80.6	81.4	81.7	81.9	81.4	81.0	79.9	79.3

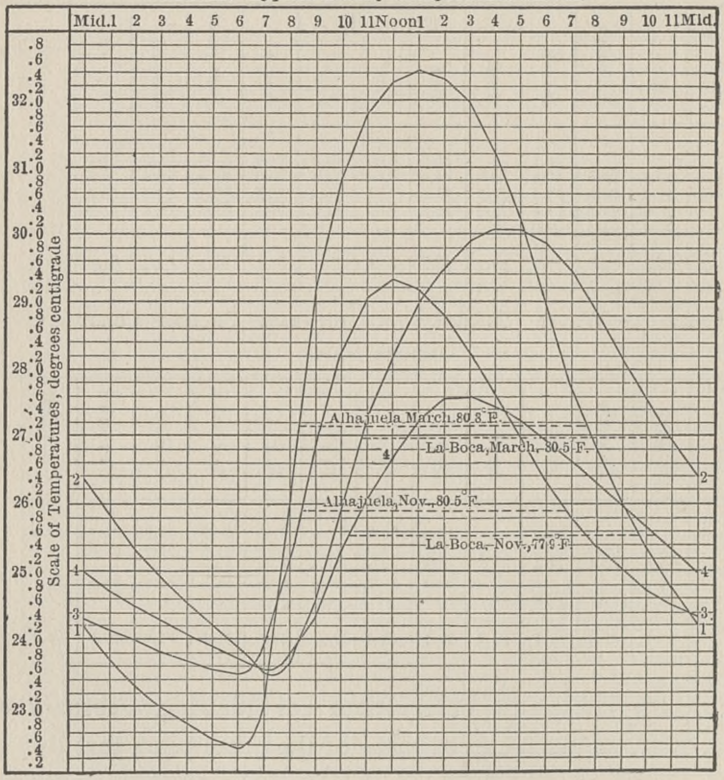
TABLE 3.—WATER TEMPERATURES ON THE PACIFIC COAST IN DEGREES FAH.

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1884	......	......	72.7	......	79.0	80.8	81.0	81.0	80.8	78.8	79.3	77.9	79.0
1885	71.1	67.6	66.9	72.1	77.7	77.9	77.4	76.8	77.4	77.0	76.6	76.1	74.5
1886	71.6	67.8	68.0	75.6	75.7	75.4	75.2	74.5	74.8	......	......	......	73.2
1887	......	......	......	......	78.4	79.2	77.9	83.5	85.8	84.2	83.7	83.1	82.2
1888	81.0	77.0	76.8	......	......	......	......	......	......	......	......	......	......
Means	71.4	67.8	69.1	73.9	77.7	78.3	77.9	79.0	79.7	80.0	79.9	79.0	76.1

line. In the tables, the observations for January, February and March, 1888, so much exceed those of the other years that they are neglected in finding the means, to avoid distorting the curve.

The tidal observations at Colon and Isle Naos covered sixty months in 1882-87. They were recorded daily and gave the following results: The most marked movements in each of these months gave for Colon a mean amplitude of 1.434 feet, with a maximum amplitude of 2.07 feet in August, 1883, and a minimum amplitude of 0.62 feet in March, 1886. At Naos these amplitudes were: mean 18.750; maximum 20.93 in October, 1883; and minimum 16.40 feet in December, 1882, respectively. At Colon only thirteen tides exceeded 1.64 feet, and at Naos only fourteen exceeded 19.68 feet, during these sixty months.

FIG. II. Typical Horary Temperature Curves.



Temperature of the air. Extraordinary uniformity is its most striking characteristic. Probably this can be shown in no way more clearly than is done by Table 4, Table 5 and Figure II. They give

TABLE 4.—TEMPERATURE AT ALHAJUELA, IN DEGREES CENTIGRADE

Hours	March							November					
	1899	1900	1901	1902	1903	1904	Mean	1899	1900	1901	1902	1903	Mean
1 a. m.	....	23.11	23.22	....	22.95	25.23	23.63	24.37	23.24	22.77	24.67	25.55	24.12
2 a. m.	....	22.86	22.82	....	22.47	24.86	23.25	24.21	23.05	22.63	24.49	25.35	23.95
3 a. m.	....	22.66	22.51	....	22.06	24.53	22.94	24.06	22.88	22.46	24.31	25.21	23.78
4 a. m.	....	22.52	22.22	....	21.83	24.40	22.74	23.91	22.70	22.31	24.14	25.10	23.63
5 a. m.	....	22.31	21.83	....	21.68	24.12	22.49	23.81	22.59	22.20	24.01	25.00	23.52
6 a. m.	....	22.22	21.53	....	21.65	24.09	**22.37**	23.77	22.48	22.17	23.90	24.95	**23.45**
7 a. m.	....	22.94	22.01	....	22.74	25.00	23.17	24.49	22.82	22.65	24.28	25.06	23.86
8 a. m.	....	26.12	25.04	....	25.44	27.33	25.98	26.16	24.50	23.92	25.40	25.74	25.14
9 a. m.	....	28.80	28.72	....	28.69	30.39	29.15	28.00	26.62	25.47	27.15	27.06	26.86
10 a. m.	....	30.18	30.62	....	30.72	31.71	30.81	29.12	28.07	26.80	28.67	28.43	28.22
11 a. m.	....	30.87	31.24	....	32.12	32.76	31.75	29.76	28.95	27.58	29.63	29.25	29.03
Noon	....	31.24	31.60	....	32.86	33.20	32.23	30.15	29.17	27.64	30.00	29.71	**29.33**
1 p. m.	....	31.34	31.78	....	33.16	33.45	**32.43**	30.23	28.79	27.12	29.95	29.73	29.18
2 p. m.	....	31.21	31.71	....	33.08	33.45	32.36	29.88	28.14	26.72	29.58	29.58	28.78
3 p. m.	....	30.90	31.24	....	32.65	33.12	31.98	29.11	27.70	26.17	28.94	29.36	28.25
4 p. m.	....	30.36	30.37	....	31.91	32.42	31.27	28.20	27.07	25.60	28.21	29.08	27.63
5 p. m.	....	29.48	29.57	....	30.76	31.10	30.23	27.42	26.42	24.95	27.40	28.66	26.97
6 p. m.	....	28.00	28.20	....	29.33	30.28	28.95	26.62	25.46	24.47	26.79	28.08	26.28
7 p. m.	....	26.75	27.06	....	27.89	29.10	27.70	26.02	24.82	24.13	26.37	27.49	25.77
8 p. m.	....	25.72	26.30	....	26.81	28.34	26.79	25.60	24.37	23.74	25.96	27.04	25.34
9 p. m.	....	25.00	25.48	....	25.82	27.53	25.96	25.28	24.06	23.44	25.62	26.59	25.00
10 p. m.	....	24.38	24.82	....	25.09	26.83	25.28	24.97	23.79	23.21	25.23	26.26	24.69
11 p. m.	....	23.94	24.24	....	24.37	26.05	24.65	24.75	23.60	23.04	25.06	25.93	24.48
Midnight	....	23.50	23.84	....	23.72	25.66	24.18	24.53	23.39	22.89	24.85	25.67	24.27
Means	....	26.52	26.58	....	27.08	28.54	27.18	26.43	25.20	24.34	26.44	27.08	25.90
Maximum	....	34.00	33.30	....	35.20	36.30	36.30	33.00	31.40	30.90	33.30	32.90	33.30
Minimum	....	18.00	18.80	....	17.70	19.90	17.70	22.50	20.70	20.70	22.10	22.90	20.70
Days of record	....	All.	All.	....	30	All.	....	All.	All.	All.	All.	All.	All.

TABLE 5.—TEMPERATURE AT LA BOCA, IN DEGREES CENTIGRADE

Hours	March							November					
	1899	1900	1901	1902	1903	1904	Mean	1899	1900	1901	1902	1903	Mean
1 a. m.	....	24.60	26 30	26.85	26.07	25.12	25.79	23.73	25.19	25.41	24.91	24.23	24.69
2 a. m.	....	24.17	25.81	26.31	25.62	24.71	25.32	23.47	24.92	25.25	24.64	24.01	24.46
3 a. m.	....	23.79	25.38	25.83	25.17	24.26	24.89	23.24	24.64	25.08	24.43	23.81	24.24
4 a. m.	....	23.47	25.01	25.42	24.81	23.95	24.53	23.00	24.42	24.93	24.20	23.64	24.04
5 a. m.	....	23.17	24.67	25.05	24.47	23.62	24.20	22.81	24.20	24.75	23.99	23.52	23.87
6 a. m.	....	22.90	24.37	24.64	24.15	23.28	23.87	22.64	24.02	24.65	23.83	23.33	23.69
7 a. m.	....	22.50	24.04	24.11	23.81	22.90	**23.47**	22.45	23.77	24.61	23.76	23.11	**23.54**
8 a. m.	....	22.95	23.93	24.25	23.74	23.14	23.60	22.59	23.83	24.87	24.04	23.16	23.70
9 a. m.	....	24.78	24.54	25.11	24.14	24.15	24.54	23.43	24.25	25.46	24.78	23.64	24.31
10 a. m.	....	26.62	25.89	26.37	25.35	25.42	25.93	24.65	25.37	26.18	25.59	24.39	25.24
11 a. m.	....	28.10	27 36	27.59	26.67	26.41	27.23	25.66	26.38	26.71	26.28	25.08	26.02
Noon	....	29.05	28 35	28.40	27.65	27.14	28.14	26.45	27.06	27.16	27.03	25.68	26.68
1 p. m.	....	29 86	29.16	29.22	28.55	28.01	28.96	27.10	27.68	27.50	27.64	26.17	27.22
2 p. m.	....	30.03	30.02	30.03	29.20	28.37	29.53	27.61	28.19	27.70	27.92	26.35	27.55
3 p. m.	....	30.06	30.65	30.53	29.77	28.49	29.90	27.71	28.26	27.72	27.95	26.33	**27.59**
4 p. m.	....	30.05	30.92	30.75	30.09	28.51	30.06	27.61	28.20	27.63	27.83	26.20	27.49
5 p. m.	....	30.02	31.00	30.75	20.15	28.43	**30.07**	27.24	27.98	27.43	27.52	25.92	27.22
6 p. m.	....	29.66	30.88	30.62	30.05	28.36	29.91	26.68	27.73	27.22	27.31	25.70	26.93
7 p. m.	....	28.87	30.28	30.38	27.74	28.12	29.48	26.06	27.46	26.95	26.95	25.56	26.60
8 p. m.	....	27.96	29.53	29.90	29.26	27.79	28.89	25.62	27.12	26.69	26.61	25.41	26.29
9 p. m.	....	27.03	28.78	29.32	28.57	27.21	28.18	25.16	26.70	26.38	26.28	25.15	25.93
10 p. m.	....	26.35	28.11	28.67	27.96	26.69	27.56	24.75	26.30	26.13	25.93	24.92	25.61
11 p. m.	....	25.70	27.49	28.04	27.28	26.11	26.92	24.42	25.90	25.88	25.56	24.64	25.28
Midnight	....	25.15	26.89	27.43	26.72	25.61	26.36	24.06	25.54	25.66	25.26	24.39	24.98
Means	....	26.53	27.47	27.73	27.04	26.08	26.97	24.92	26.04	26.16	25.84	24.76	25.54
Maximum	....	32.10	33.00	32.60	31.80	30.50	33.00	31.20	31.20	30.00	30.80	28.90	31.20
Minimum	....	20.00	21.70	22.10	22.10	21.70	20.00	20.60	22.10	23.10	22.00	21.80	20.60
Days of record	....	All.	30	All.	All.	All.	....	All.	24	All.	All.	All.	....

TABLE 6.—SUMMARY OF MONTHLY MEAN TEMPERATURES

Month	Alhajuela						La Boca					
	No. of years	Mean Daily	Mean hottest		Mean coolest		No. of years	Mean Daily	Mean hottest		Mean coolest	
		°F.	Hour	°F.	Hour	°F.		°F.	Hour	°F.	Hour	°F.
January	5	78.8	1 p. m.	86.3	6 a. m.	72.1	5	79.1	4 p. m.	84.0	7 a. m.	74.0
February	4	80.6	1 p. m.	89.3	6 a. m.	72.8	5	80.2	4 p. m.	86.0	7 a. m.	74.3
March	4	80.9	1 p. m.	90.4	6 a. m.	72.3	5	80.5	5 p. m.	86.1	7 a. m.	74.3
April	5	81.1	1 p. m.	88.7	6 a. m.	74.3	5	81.1	4 p. m.	85.9	7 a. m.	76.0
May	3	79.0	11 a. m.	85.3	5 a. m.	73.9	3	80.1	2 p. m.	83.6	7 a. m.	76.4
June	4	79.7	noon	86.6	6 a. m.	74.5	4	80.7	3 p. m.	84.4	7 a. m.	76.6
July	5	79.1	1 p. m.	84.7	6 a. m.	74.7	5	79.8	2 p. m.	84.0	6 a. m.	76.1
August	5	79.7	noon	86.1	6 a. m.	74.8	5	78.9	2 p. m.	82.7	7 a. m.	75.0
September	5	79.5	noon	86.6	6 a. m.	74.4	5	79.4	2 p. m.	83.6	7 a. m.	75.2
October	5	78.8	noon	85.6	6 a. m.	73.7	5	78.4	2 p. m.	82.6	7 a. m.	74.4
November	5	78.7	noon	74.2	6 a. m.	74.2	5	77.9	3 p. m.	81.6	6 a. m.	74.6
December	5	79.0	1 p. m.	86.2	6 a. m.	72.7	5	79.0	4 p. m.	83.6	7 a. m.	74.2
Means	4.6	79.6	Noon	86.7	6 a. m.	73.7	4.8	79.6	3 p. m.	84.0	7 a. m.	75.1

the mean monthly reading of the thermometer at each hour of the day for several successive years at localities which are typical of the climate in the interior and on the Pacific coast. The months of March and November are selected, as they represent extreme conditions in respect to rainfall. The figures are based on observations recorded by self-registering thermometers; and in the Monthly Weather Review for June, 1904, will be found corresponding series for the remaining months of the year. A general summary of the monthly means is given in Table 6.

Table 7 briefly recapitulates all the temperature observations made on the Isthmus up to the end of 1902. No better evidence of the uniformity of the monthly means throughout the entire region could be desired.

TABLE 7.—SUMMARY OF AIR TEMPERATURES ON THE ISTHMUS

Month	Colon, 92 months	Gamboa, 58 months	Alhajuela, 39 months	Panama, 9 months	La Boca, 41 months	Naos, 70 months	Mean	
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°F.
January	26.25	24.10	24.96	26.17	26.20	26.60	25.71	78.28
February	26.18	23.60	26.06	26.25	26.79	26.15	25.84	78.51
March	26.47	24.15	26.55	26.62	27.25	26.33	26.23	79.21
April	26.48	24.90	27.05	27.25	27.69	27.65	26.84	80.31
May	26.73	26.85	25.55	27.07	27.01	27.90	26.85	80.33
June	26.73	27.70	26.21	26.69	27.23	28.85	27.23	81.01
July	26.77	26.75	26.02	....	26.69	28.31	26.91	80.44
August	26.23	26.60	26.20	....	26.10	28.00	26.63	79.93
September	26.57	27.15	25.97	....	26.46	27.94	26.82	80.28
October	26.18	26.55	25.46	26.45	25.84	27.45	26.32	79.38
November	26.10	26.80	25.60	26.01	25.79	26.80	26.18	79.12
December	26.47	25.75	25.76	25.78	26.48	26.80	26.17	79.11
Means	26.43	25.91	25.95	26.48	26.63	27.40	26.48	79.66

The observations made by the U. S. Weather Bureau, hourly during the two years 1899 and 1900, at Barbados, Trinidad and Curaçao, all at about the same altitude and latitude as the Isthmus, throw light upon the probable influence upon the temperature of the latter exerted by the near vicinity of the Pacific ocean. The reduction of these records in Table 8 was made to assist in the study.

TABLE 8.—OBSERVED AIR TEMPERATURES NEAR SEA LEVEL, NORTH SHORE OF SOUTH AMERICA

Month	Barbados			Trinidad			Curaçao			Mean	
	1899	1900	Mean	1899	1900	Mean	1899	1900	Mean		
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°C.
January	76.2	79.9	78.0	76.3	77.9	77.1	77.3	79.8	78.1	77.73	25.41
February	75.7	77.5	76.6	76.4	77.5	77.0	76.9	78.7	77.8	77.13	25.08
March	76.0	77.8	76.9	76.8	78.2	77.5	77.0	78.4	77.7	77.37	25.21
April	77.7	79.4	78.6	78.0	79.4	78.7	78.9	80.1	79.5	78.93	26.08
May	79.4	80.0	79.7	79.6	79.2	79.4	79.8	81.3	80.5	79.87	26.60
June	79.6	80.1	79.8	78.6	78.1	78.4	80.5	82.1	81.3	79.83	26.58
July	80.3	80.2	80.3	79.1	......	79.1	81.4	81.3	81.4	80.27	26.82
August	80.8	80.6	80.7	79.5	80.2	79.9	81.9	82.4	82.1	80.90	27.10
September	80.7	80.9	80.8	79.9	79.7	79.8	82.8	82.4	82.6	81.07	27.21
October	80.0	80.0	80.0	80.6	79.5	80.0	82.0	81.8	81.9	80.63	26.93
November	80.0	79.2	79.6	79.0	78.4	78.7	81.5	80.3	80.9	79.73	26.52
December	78.2	79.9	79.0	78.3	79.0	78.7	79.3	79.7	79.5	79.07	26.08
Means	78.7	79.6	79.2	78.3	78.7	78.7	79.9	80.6	80.3	79.39	26.30

Finally to compare the Isthmian temperatures with those of some other well determined regions Table 9 was compiled, chiefly from

TABLE 9.—TEMPERATURES, TEMPERATE AND TROPICAL

Localities	Approximate latitude	Years of observation	Average temperature				Max. recorded
			Annual	Hottest month	Coldest month	Difference	
	°		°F.	°F.	°F.	°F.	°F.
Washington	39	25	54.7	76.9	33.2	43.7	104
New Orleans	30	25	68.8	82.4	53.3	29.1	99
Key West	25	21	77.5	84.4	70.5	13.9	....
Assuan or Wadi Halfa	23	....	80.0	94.8	64.0	30.8	119
Habana	23	10	76.8	82.4	70.3	12.1	101
San Juan, P. R.	18	12	78.8	81.5	75.7	5.8	101
Kingston, Jamaica	18	10	78.1	81.1	74.6	6.5	....
Barbados	13	20	75.6	76.9	73.4	3.5	....
Cayenne	4	1	79.7	82.0	77.1	4.9	....
Madras	13	10	82.0	87.5	75.2	12.3	....
Singapore	1	3	80.2	81.7	78.6	3.1	....
Manila	15	17	80.0	84.0	77.0	7.0	100
Port au Prince	19	7	79.0	81.9	75.8	6.1	....
Isthmus of Panama	9	26	79.7	81.0	78.3	2.7	99

Bulletin No. 22 (serial No. 163) of the United States Weather Bureau, published in 1898.

In his elaborate study of inter-tropical temperatures (Der Tagliche Gang der Temperatur in der Inneren Tropenzone. Wien 1905.) Mr. Julius Hann publishes the monthly means, together with the mean hourly variations therefrom, the elevations above sea level, and the latitudes and longitudes of thirty stations. Seven of them are in East Africa, five in West Africa, seven in East Asia and North Australia, one in the Pacific, five in Central America, one in the West Indies, and four in South America,—thus circumscribing the globe. Only seven show a higher annual temperature than does Alhajuela, and only one a smaller monthly variation. This latter station is Batavia, with a record of 35 years, showing an annual mean temperature of 78°.8 Fah., and a maximum monthly mean variation of only 2°.0: these figures for Alhajuela are 79°.6 and 2°.5.

Elements causing uniformity. In view of so exceptional uniformity of mean monthly and annual temperatures, it is not without interest to see if the application of general principles will explain the relative influence of the elements combining to produce it; and the following study was made accordingly:

The essential elements which determine this uniformity are the direct heat received from the sun; the influence of the excessive volume of aqueous vapor held in suspension in the atmosphere, and the influence of the two great seas which wash the shores of the narrow belt of land constituting the Isthmus. The influence of the seas depends upon their varying absolute temperatures and on the movements of the atmosphere; as these, in a large measure, regulate the effects of the oceans in different months. The available statistics, collected chiefly by the two Panama Canal companies, throw much light upon the relative influence of these several agencies, and are sufficiently complete to warrant an attempt at a mathematical treatment of the problem. Each element will be considered in turn.

Monthly mean temperatures, as determined from hourly observations, refer to the middle of each month. Hence, the relative intensity of the solar energy received during the month may be regarded as proportional to the sine of the altitude of the sun at noon, and its relative duration as proportional to the length of the time that it is above the horizon, on that day. Thus in latitude 9° north, the sun at noon is at the zenith twice during the year, once on April 13, when it is journeying northward to reach its summer solstice on June 21, and again on August 29, when returning toward its winter solstice, which it reaches on December 21. The direct heat transmitted at these altitudes is then proportional to the sines of 90°, 75° 41′, and 57° 24′, or to the numbers 1.00, 0.97, and 0.84 for the zenith, the summer solstice, and the winter solstice, respectively. It is, however, to be noted that the length of day, and hence the duration of solar radiation, attains its maximum in June and its minimum in December; and that this element therefore tends to reduce the natural fall of temperature during the northward journey of the sun, and to augment it during the approach to his southern limit. Furthermore the absolute distance between the earth and the sun is subject to a slight variation at different periods of the annual rotation, but the relative intensity of the solar energy being inversely proportional to the square of the radii vectores, this variation is easily estimated. The numerical values of these several elements for each month are given in the first eight columns of Table 10.

But the temperature of the air, as registered by the thermometer, is affected by the modifying influence of the aqueous vapor held in suspension, which opposes great resistance to the energy radiated from the sun by day, and still more to that radiated back from the earth both by day and by night. By day this vapor tends to largely reduce, and by night to largely increase, the temperature of the air at the earth's surface. Unfortunately a trustworthy estimate of the numerical value of this varying vaporous element is far more difficult than for solar radiation; but its influence cannot be ignored in the study, although the available data can only be regarded as approximate. The actual measurements on the Isthmus consist of observations for one year, made by the old Canal Company at Colon in 1881, and for eight months at this place by the United States Weather Bureau from October, 1898, to May, 1899. Both series indicate, as is usual in similar climates, a decided excess in the months of heavy rains; the former series gives a mean relative humidity of 0.77 for January, February, March, and April, and of 0.86 for the rest of the year; the corresponding figures of the Weather Bureau are 0.83 and 0.88. It would seem therefore that the best available estimate to adopt for relative humidity is a mean between the two series of measurements, giving 0.80 in the

TABLE 10.—INFLUENCE OF SUN AND HUMIDITY ON TEMPERATURE FOR THE MIDDLE DAY OF EACH MONTH

Month	Radius Vector of the earth	Latitude, 9° north			Relative length of—		Relative intensity of solar energy	Relative humidity	Effective ratios by—	
		Sun rises	Sun sets	Altitude at noon	Day	Night			Day	Night
		h. m.	h. m.	° ′						
January	0.9835	6 22	5 58	S. 59 53	0.917	0.993	1.034	0.80	1.025	0.821
February	0.9880	6 23	6 07	S. 68 01	0.927	0.983	1.025	0.80	1.102	0.805
March	0.9950	6 06	6 13	S. 78 54	0.958	0.952	1.011	0.80	1.188	0.770
April	1.0040	5 51	6 10	N. 89 13	0.974	0.936	0.993	0.80	1.210	0.744
May	1.0110	5 41	6 12	N. 80 07	0.990	0.920	0.978	0.83	1.150	0.747
June	1.0160	5 41	6 20	N. 75 41	1.000	0.909	0.969	0.87	1.080	0.767
July	1.0160	5 52	6 19	N. 77 28	0.984	0.925	0.968	0.87	1.069	0.779
August	1.0130	5 53	6 14	N. 84 57	0.976	0.933	0.975	0.87	1.087	0.791
September	1.0060	5 52	5 57	S. 84 01	0.955	0.955	0.989	0.87	1.080	0.822
October	0.9970	5 50	5 41	S. 72 28	0.937	0.973	1.006	0.87	1.032	0.851
November	0.9890	5 55	5 34	S. 62 29	0.921	0.989	1.023	0.87	0.961	0.879
December	0.9840	6 10	5 41	S. 57 43	0.911	1.000	1.033	0.83	0.958	0.857

four dry months, 0.87 in six of the rainy months, and 0.83 in the intermediate months of December and May.

In introducing this element into the study it is needful to note that the effect of aqueous vapor in suspension upon the temperature of the air at the earth's surface is reversed every twelve hours. By day it tends to reduce the reading of the thermometer by absorbing part of the solar radiation, and to increase it by checking radiation from the earth; but as the former is much the more potent agency the aggregate influence is to reduce the reading. In other words, the resulting temperature is inversely proportional to a function of the aqueous vapor in suspension. By night the effect is wholly to increase the reading of the thermometer, by checking terrestrial radiation. In other words, the resulting temperature is then directly proportional to some function of this quantity. Although it is well known that the obstructive action in question is much less effective against solar than against terrestrial radiation, no coefficient applicable to the entire atmosphere has been established. It is, however, to be noted that in using the same numerical value for relative humidity by day and by night a corrective coefficient is virtually introduced, since by day the computation deals with the difference between the two opposing radiations and by night with only one of them. Furthermore, absolute humidity is less by night than by day. Table 10 exhibits the numerical values of the elements entering into the study, and, in the last two columns, the resulting ratios indicating the relative influence upon monthly mean temperatures exerted jointly by the sun and by humidity. The values by day represent the products of the sine of the sun's altitude at noon by the relative length of day and by the relative solar energy, the whole divided by relative humidity; by night they represent the product of the relative length of night by the relative solar energy and by relative humidity. If these ratios be multiplied by such numbers as will give an annual mean temperature similar to that actually observed, or by 24.5 for day and 32.7 for night, the results will be scales for monthly means representing the relative combined effect of the agencies in question in the several months. Such figures appear in Table 12.

It remains to consider the influence of the oceans bordering the Isthmus. As stated above, the old Canal Company made daily observations of the temperature of the water at Colon and at Naos for four years, and the monthly means appear in Table 3 and are repeated in Table 11. The general movements of the atmosphere, which in a large measure determine the influence of oceans upon neighboring shore climates, are here governed by the locus of the ascending current of warm air which follows the sun in its travels north and south between the tropics. When the sun is north of the Isthmus southerly winds prevail, and when south, northerly winds. As also stated above, observations upon the direction of the movement were made daily at Colon by the old Canal Company, and the results were confirmed later by the United States Weather Bureau. The resulting percentages of winds blowing from the sea during each month are given in Table 11, together with the effective monthly departures from the annual mean ocean temperature, the latter being the product of the observed departures by these percentages. The final

TABLE 11.—INFLUENCE OF ADJACENT SEAS ON ISTHMIAN TEMPERATURE

Month	Caribbean Sea				Bay of Panama			
	Water temperature	Per cent. of sea breeze	Effective departure	Active temperature	Water temperature	Per cent. of sea breeze	Effective departure	Active temperature
	°C.		°C.	°C.	°C.		°C.	°C.
January	24.5	99	−1.8	24.5	21.9	00	0.0	24.5
February	24.3	98	−2.0	24.3	19.9	00	0.0	24.5
March	25.0	95	−1.2	25.1	20.6	01	0.0	24.5
April	25.2	90	−1.0	25.3	23.3	04	0.0	24.5
May	26.0	45	−0.1	26.2	25.4	40	+0.4	24.9
June	27.0	27	+0.2	26.5	25.7	51	+0.6	25.1
July	27.4	36	+0.4	26.7	25.5	53	+0.5	25.0
August	27.6	38	+0.5	26.8	26.1	51	+0.8	25.3
September	27.7	31	+0.4	26.7	26.5	56	+1.1	25.6
October	27.4	01	+0.1	26.4	26.7	74	+1.6	26.1
November	27.2	21	+0.2	26.5	26.6	67	+1.4	25.9
December	26.6	78	+0.2	26.5	26.1	12	+0.2	24.7
Means	26.3	....	....	26.0	24.5	....	....	25.0

column for each ocean gives a scale of monthly mean ocean temperatures representing for each month the relative effective influence upon the shore climate,—found by adding to the annual mean the effective monthly departures.

The results of this analysis of the mean monthly temperatures of the Isthmus are presented in Table 12, of which the first four columns recapitulate the typical scales discussed above. The fifth column is derived from them by taking a mean between the mean for day and night and the two ocean scales, and subtracting 0.64 of a degree in order to reduce the annual mean to that shown by the observations. The sixth column repeats the observed mean temperatures given in Table 7. Then follows a column showing discrepancies between analysis and observation. The last three columns repeat the results, in degrees Fahrenheit, to which the coastwise average on the north shore of South America is added for convenience of comparison.

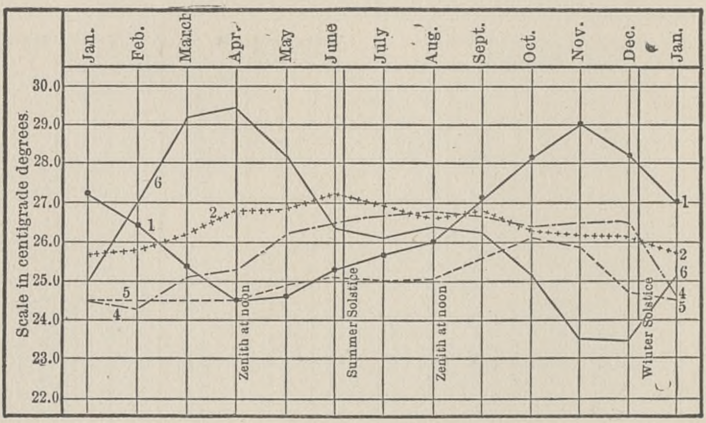
The small discrepancies shown in this table, averaging only one-third of a degree, Centigrade, regardless of sign, with a maximum of only three-quarters of a degree, between the indications derived

TABLE 12.—ANALYSIS OF AIR TEMPERATURES.

Month	Active elements in deg. C.				Resultants, in deg. C.			Temperature in deg. F.		
								Isthmus		
	By day	By night	Caribbean Sea	Pacific	Computed	Observed	Difference	Comp'd	Obs'd	South American Coast
	°	°	°	°	°	°	°	°	°	°
January	25.10	27.08	24.50	24.50	25.67	25.71	+0.04	77.21	78.28	77.73
February	27.00	26.58	24.30	24.50	25.84	25.84	0.00	78.51	78.51	77.13
March	29.10	25.42	25.10	24.50	26.26	26.23	—0.03	79.27	79.21	77.37
April	29.64	24.55	25.30	24.50	26.27	26.84	+0.57	79.29	80.31	78.93
May	28.17	24.66	26.20	24.90	26.48	26.85	+0.37	79.66	80.33	79.87
June	26.45	25.30	26.50	25.10	26.47	27.23	+0.76	79.65	81.01	79.83
July	26.20	25.71	26 70	25.00	26.53	26.91	+0.38	79.75	80.44	80.27
August	26.66	26.00	26.80	25.03	26.48	26.63	+0.15	79.66	79.93	80.90
September	26.46	27.12	26.70	25.60	27.00	26.82	—0.18	80.60	80.28	81.07
October	25.29	28.08	26.40	26.10	27.03	26.32	—0.71	80.65	79.38	80.63
November	23.54	29.02	26.50	25.90	26.87	26.18	—0.69	80.37	79.12	79.73
December	23.47	28,28	26.50	24.70	26.33	26.17	—0.16	79.39	79.11	79.07
Means	26.48	26.54	26.00	25.00	26.48	26.48	0.34	79.66	79.66	79.39

from an analysis of the forces in action and the results of numerous and well distributed observations would seem to warrant the belief that the former are determined with sufficient accuracy to make known their respective agencies in modifying the climate of the Isthmus. The curves on Fig. III present to the eye the data contained in the more important columns of the table. If the direct action of the sun as modified by humidity alone be considered the maximum temperature would occur at the first zenith transit (April 13), with a reading of 85°.3 Fah., while the minimum would occur at the winter solstice (December 22), with a reading of 74°.2 Fah., indicating an annual range of 11°.1 Fah.; but including the influence of humidity at night these readings would become 80°.8 and 78°.6, indicating a range of 2°.2; but, including also the influence of the two seas, the date of maximum shifts, by a small difference, to the second zenith transit (August 29), with an extreme annual range of 3°.4 Fah. That actually observed (between June and January) was 2°.7 Fah. On the northern shore of South America the observations indicate a range of 2°.13 between the August

FIG. III. INFLUENCE OF FACTORS UPON MONTHLY TEMPERATURES ON THE ISTHMUS OF PANAMA

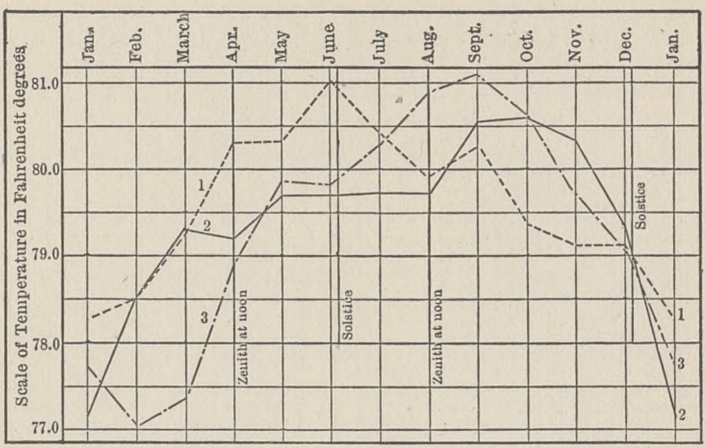


Each curve is given a number to assist in distinguishing between them, and to enable an easy reference to be made to the table containing the figures represented. Thus curve (1) shows the influence of the humidity of the air during the night time (see table 12, column 3); curve (2) the observed temperature (see table 12, column 7); curve (4) temperature of the Caribbean Sea (see table 12, column 4); curve (5) temperature of the Bay of Panama (see table 12, column 5); curve (6) influence of humidity and sunshine by day (see table 12, column 2).

transit and February, which is the coolest month perhaps from the elimination of the agency of the Pacific. The curves indicating the influence of the two oceans show that the Atlantic is much the more important, and the close resemblance, shown by Fig. 4, between the temperatures prevailing on the Isthmus and on the northern shore confirm this conclusion. The northerly winds prevailing in the first four months of the year effectually prevent the Pacific, then relatively cold, from moderating the temperature at Panama. The joint influence of varying humidity and varying length of night is a more powerful factor in effecting the nearly unvarying annual temperature of the Isthmus than perhaps has been appreciated hitherto. The effect of the varying distance of the sun can be recognized, but it only modifies the climate very slightly.

Diurnal variation in temperature.—Although at any given locality in corresponding months of different years, the horary curves

FIG. IV. COMPARISON OF TEMPERATURES, ISTHMUS OF PANAMA AND NORTHERN SHORE OF SOUTH AMERICA



Each curve is given a number to assist in distinguishing between them, and to enable an easy reference to be made to the table containing the figures represented. Thus curve (1) shows the temperature observed on the Isthmus of Panama, 309 months (see table 12, column 10); curve (2) shows that computed (see table 12, column 9); curve (3) shows that on the northern coast of South America, 71 months (Curaçoa, Trinidad, Barbados) see table 12, column 11.

show marked similarity, as is apparent from Tables 4 and 5, when the locality or season is changed characteristic differences are developed. The observations with self-recording thermometers of the Richard type at Colon, Alhajuela, Panama and La Boca have made these differences known with precision, and as they are not without importance in regulating the hours of work, Table 13 and Figure II have been prepared to indicate them. The observations at Colon were made by the United States Weather Bureau from October, 1898, to May, 1899; and all the others, by the New Company. The latter were recorded in local time, and the former in that of the 75th meridian, which makes it needful to deduct nineteen minutes from the Colon observations before they can be compared with the others. For this reason the curve is omitted on Fig. II.

TABLE 13.—HORARY VARIATIONS IN TEMPERATURE, IN DEGREES FAH.

Hour	Dry Season January-April				Rainy season May-December				Extreme variations March and November			
	Colon 4 months	Alhajuela 18 months	Panama 4 months	La Boca 20 months	Colon 4 months	Alhajuela 37 months	Panama 5 months	La Boca 37 months	Alhajuela March(4)	Alhajuela Nov.(5)	La Boca March(5)	La Boca Nov. (5)
1 a. m.	77.50	74.9	77.32	78.2	76.37	75.4	78.44	77.6	74.4	75.3	78.4	76.4
2 a. m.	77.40	74.4	76.95	77.5	75.92	75.2	78.26	77.1	73.7	75.1	77.5	76.0
3 a. m.	77.14	73.8	76.55	76.8	75.56	74.7	78.01	76.6	73.2	74.8	76.8	75.5
4 a. m.	77.04	73.4	76.26	76.2	75.29	74.4	77.81	76.2	72.9	74.5	76.1	75.2
5 a. m.	76.68	73.0	76.01	75.7	74.98	74.3	77.77	75.9	72.5	74.3	75 5	74.9
6 a. m.	76.55*	72.8*	75.76	75.2	74.93*	74.2*	77.47*	75.5	72.3*	74.2*	74.9	74.6
7 a. m.	77.00	74.3	75.69*	74.6*	75.56	75.4	77.52	75.2*	73.8	74.9	74.2*	74.3*
8 a. m.	78.26	78.8	76.39	74.7	77.90	76.3	78.12	75.2*	78.7	77.1	74.5	74.6
9 a. m.	80.28	83.4	78.53	76.3	79.84	81.5	79.16	77.1	84.4	80.3	76.1	75.7
10 a. m.	81 45	85.9	80.69	78.5	81.46	83.8	80.20	78.8	87.5	82.7	78.6	77.3
11 a. m.	82.38	87.4	82.18	80.6	82.49	85.2	81.03	79.2	89.1	84.2	80.9	78.8
Noon	82.80*	82.2	82.98	82.0	83.12*	85.7*	81.32	81.6	90.0	84.7*	82.5	79.9
1 p. m.	82.58	88.3	83.39	83.4	83.12*	85.4	81.46	82.6	90.4*	84.4	84.6	80.9
2 p. m.	82.13	88.5*	83.88	84.5	82.96	84.5	81.61*	83.2*	90.2	83.7	85.2	81.5
3 p. m.	81.82	87.9	84.60	85.3	82.08	83.6	81.50	83.2*	89.6	82.7	85.9	81.6*
4 p. m.	81.36	86.9	84.70*	85.5*	81.54	82.5	81.32	82.8	88.3	81.6	86.1*	81.5
5 p. m.	80.38	85.1	84.15	85.4	80.56	81.4	80.92	82.4	86.4	80.5	86.1*	80.9
6 p. m.	79.43	83.1	83.21	85.1	79.25	80.0	80.53	81.8	84.1	79 2	85.9	80.4
7 p. m.	78.84	81.1	81.81	84 3	78.48	79.0	80.10	81.4	81.8	78.3	85.1	79.8
8 p. m.	78.76	79.7	80.51	83.4	78.26	78.0	79.74	80.8	80.2	77.5	84.0	79.3
9 p. m.	78.35	78.2	79.61	82.2	77.72	77.3	79.45	80.1	78.7	77.0	82.6	78.6
10 p. m.	78.26	77.3	78.82	81.2	77.36	76.8	79.20	79.6	77.4	76.4	81.6	78.0
11 p. m	78.08	76.4	78.17	80.1	77.09	76.2	78.91	78.8	76.3	76.0	80.4	77.4
Midnight	78.90	75.7	77.68	79.7	76.73	75.7	78.66	78.2	75.4	75.6	79.3	76.9
Means	79.30	80.4	70.83	80.3	78.68	79.0	79.52	79.2	80.9	78.5	80.5	77.9
Max.	87.08	98.2	88.88	95.4	89.96	96.6	89.78	91.0	97.4	91.9	86.9	88.2
Min.	68.00	63.8	71.70	68.0	69.08	66.0	74.84	68.0	63.8	69.3	68.0	69.1

During the five years covered by these records the months of March and November showed the extreme variations in the hygrometric conditions, and they are therefore added to Table 13, and selected for the Figure.

This table representing over 85,000 readings of the thermometer leaves little to be added in words. At Colon no marked difference as to hours or range of temperature is noted between the seasons, but in the interior and on the Pacific coast the range is greater, and the hottest and coolest hours occur later in the dry than in the rainy season. The asterisks in the table, indicating maxima and minima, make this apparent.

Alhajuela, midway between the oceans and only 144 feet above tide, is well suited to represent the climate of the interior, where is located all the heavy work of the canal. Here the temperature at sunrise in the dry season is about 73° F.; it soon rises rapidly, attaining about 89° F. at 2 p.m.; after this it falls rapidly to about 83° F. at sunset, and then subsides gradually to the minimum at sunrise. During the rainy season the temperature at sunrise is about 75° F.; it rapidly reaches a maximum at noon, about 85° F., and then falls very slowly to sunset, and to the minimum at sunrise. Thus, during the dry season the daily temperature has a larger range and a later maximum than when rains prevail.

At La Boca, situated on the Bay of Panama, the minimum temperature occurs later, or at about an hour after sunrise, being then about 75° F. in both the dry and the rainy seasons. The maximum in the dry season, 86° F., is reached at about 4 p.m., and in the rainy season, 83° F., at about half past 2 p.m. The rate of fall is more gradual than at Alhajuela, the mercury receding at sunset in the dry season only to about 84° F., and in the rainy season only to about 81° F. In short, the changes on the Pacific coast are less extreme and are later than in the interior, but the daily average is about the same, 79° F.

Unfortunately the observations at Colon, and at Panama as well, do not cover an entire year, which renders a comparison by seasons uncertain. The averages, however, show that no material difference in climate exists on any part of the canal route.

The Alhajuela type of horary change, early minimum and maximum and rapid rate of variation, prevails at Barbados and Curaçao, and hence the wide difference at La Boca must be attributed to the influence of the Pacific. On the contrary, the daily range at Barbados is identical with that at La Boca, while that at Curaçao is less than either, being only about 6° or 7°, as compared with 11° or 12° in the interior of the Isthmus. Nights averaging 3° or 4° cooler are a distinct advantage for the canal.

As in the case with monthly means, the changes of temperature from hour to hour and from day to day are subject to much less variation on the Isthmus than in regions more remote from the equator; and, therefore, Table 13 conveys a more definite idea of the climate than would similar compilations for localities in the United States. It should, however, be remembered that they are based on observations made where the thermometers were not subjected to direct solar radiation; laborers exposed to the sun would experience much higher temperatures.

Barometric pressure.—The uniformity of barometric pressure on the Isthmus is even more extraordinary than that of the air temperature. Thus, during the five years in which it was recorded at Alhajuela, by barograph, the extreme oscillation ranged from 30.12 to 29.68 inches, including the normal horary variation of about one-tenth of an inch. These extremes occurred in the dry season, February and April.

It should be noted that the barometric records, as given in Table 14, should be reduced by 5.65 millimeters for instrumental error, and increased about 3.7 millimeters for height above mean tide (143 feet), making a total residual correction of —1.95 millimeters to reduce to sea level. These records indicate 29.84 inches for the latter. The U. S. Weather Bureau from eight months' records at Colon found it to be 29.87 inches. Figures in full-face type in the table indicate extremes. The full annual record is given for January, to illustrate the uniformity from year to year. Two years are lacking for May and one for June; the rest are complete. If this uniformity had been understood, much use of the barometer might well have been made to determine heights in the preliminary reconnaissances, which the dense undergrowth rendered exceptionally difficult.

TABLE 14.—BAROMETRIC PRESSURE AT ALHAJUELA, IN MILLIMETERS

Hours	January						Means for five years										
	1900	1901	1902	1903	1904	Mean	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1 a. m.	760.70	761.50	759.70	760.30	759.08	760.26	760.42	760.26	759.40	759.86	759.89	760.24	760.25	760.55	760.49	760.17	760.12
2 a. m.	60.50	61.30	59.60	60.14	58.92	60.09	60.22	60.04	59.18	59.64	59.66	59.97	59.98	60.24	60.23	59.90	59.91
3 a. m.	60.20	61.20	59.50	60.00	58.81	**59.94**	**60.09**	59.87	**58.99**	**59.54**	59.52	59.82	59.83	**60.09**	**60.07**	**59.74**	**59.74**
4 a. m.	60.10	61.30	59.50	60.08	58.84	59.96	**60.09**	**59.80**	59.02	59.57	**59.49**	**59.73**	**59.81**	60.13	60.14	59.82	59.76
5 a. m.	60.20	61.60	59.60	60.27	58.94	60.12	60.25	59.94	59.14	59.71	59.64	59.83	59.99	60.29	60.30	60.00	59.95
6 a. m.	60.50	61.90	59.80	60.58	59.28	60.41	60.52	60.24	59.42	60.04	59.89	60.05	60.24	60.60	60.63	60.31	60.21
7 a. m.	61.10	62.20	60.00	60.91	59.66	60.77	60.88	60.57	59.73	60.32	60.18	60.36	60.51	60.89	60.94	60.69	60.52
8 a. m.	61.20	62.30	60.10	61.08	59.85	**60.91**	**61.07**	**60.80**	59.93	**60.39**	**60.24**	**60.47**	**60.67**	**61.16**	**61.13**	60.90	**60.71**
9 a. m.	61.50	61.80	60.00	60.77	59.63	60.74	60.91	60.68	**59.99**	60.29	60.09	60.38	60.50	61.10	61.10	**60.91**	60.55
10 a. m.	61.40	61.20	59.70	60.18	59.13	60.32	60.55	60.31	59.45	60.03	59.73	60.14	60.14	60.69	60.73	60.34	60.16
11 a. m.	61.30	60.50	59.30	59.51	58.46	59.81	59.96	59.72	59.04	59.65	59.21	59.72	59.66	60.07	60.30	59.91	59.62
Noon	60.90	60.00	58.80	58.80	57.96	59.29	59.31	59.13	58.59	59.24	58.83	59.34	59.17	59.45	59.49	59.32	59.08
1 p. m.	60.50	59.40	58.40	58.22	57.20	58.74	58.84	58.51	58.05	58.79	58.47	58.91	58.75	58.90	58.98	58.83	58.53
2 p. m.	59.90	58.90	58.20	57.68	56.60	58.26	58.23	57.86	57.49	58.44	58.19	58.54	58.41	58.46	58.61	58.43	58.07
3 p. m.	59.60	58.70	58.10	57.49	56.49	**58.08**	57.82	57.42	57.17	58.21	57.97	58.31	58.22	**58.27**	**58.40**	**58.30**	**57.88**
4 p. m.	59.50	58.90	58.20	57.62	56.35	58.11	**57.76**	**57.32**	**57.03**	**58.19**	**57.96**	**58.27**	**58.19**	58.39	58.50	58.40	57.95
5 p. m.	59.70	59.20	58.40	57.96	56.69	58.39	57.96	57.47	57.15	58.34	58.15	58.41	58.44	58.63	58.77	58.65	58.15
6 p. m.	60.00	59.80	58.80	58.54	57.12	58.85	58.48	57.90	57.53	58.74	58.53	58.77	58.86	59.09	59.16	59.11	58.65
7 p. m.	60.30	60.40	59.30	59.18	57.62	59.36	58.99	58.49	58.10	59.18	59.01	59.25	59.34	59.57	59.65	59.59	59.13
8 p. m.	60.70	61.00	59.80	59.76	58.14	59.88	59.52	59.10	58.60	59.61	59.41	59.72	59.82	60.05	60.14	60.04	59.66
9 p. m.	61.10	61.40	60.00	60.20	58.59	60.26	60.00	59.56	59.06	59.93	59.75	60.12	60.17	60.48	60.54	60.47	60.03
10 p. m.	61.20	61.80	60.10	60.57	58.93	60.52	60.37	60.08	59.40	60.15	59.98	60.40	60.48	60.75	60.77	**60.66**	60.26
11 p. m.	61.20	61.90	60.10	60.53	59.10	**60.57**	**60.57**	60.35	**59.60**	**60.24**	**60.09**	**60.51**	**60.55**	**60.87**	**60.86**	60.62	**60.33**
Midnight	61.10	61.70	59.90	60.55	59.15	60.48	**60.57**	**60.42**	59.57	60.09	60.08	60.48	60.48	60.73	60.71	60.46	60.26
Means	60.60	60.80	59.40	59.62	58.36	59.75	59.73	59.41	58.78	59.51	59.33	59.66	59.68	59.98	60.03	59.82	59.56
Maximum	63.40	63.40	61.90	64.80	62.10	64.80	64.90	63.80	63.00	53.80	63.00	63.10	63.80	63.00	63.00	64.20	63.90
Minimum	57.90	57.30	56.10	55.10	55.00	55.00	54.00	54.20	53.80	55.60	54.90	54.50	55.20	55.00	55.50	53.80	54.00
Days of record	20	All.	26	All.	17	......	......	.....	.....	All.	......	......	All.	All.	All.	All.	All.

If the horary curves of Table 14 be studied, it will be seen that the same characteristic differences exist between those of the two seasons as have already been noted between the temperature horary curves,—the hours of maximum and minimum occur a little later, and the range of oscillation is a trifle greater in the dry than in the rainy season. The sun thus registers his influence even in this delicate variation in the height of the mercurial column, that all told hardly exceeds one-tenth of an inch. This is apparent from Figure V, which presents the results of a study, at their date, of between three and four years of the records consolidated in Table 14.

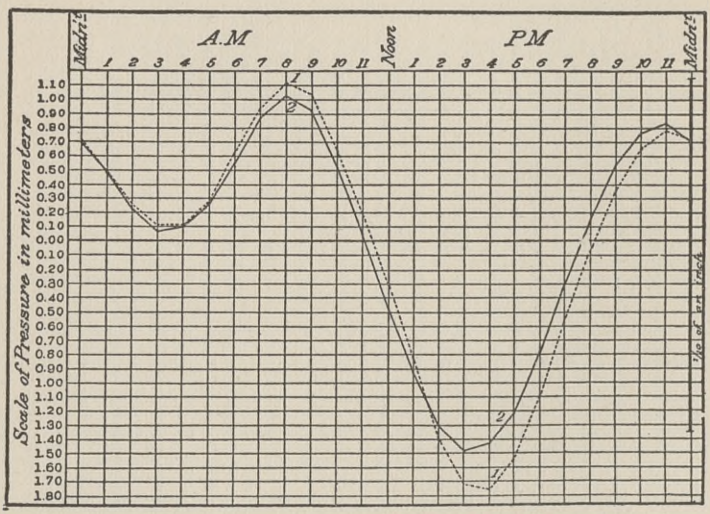


FIG. V. Diurnal curve of barometric pressure at Alhajuela. Dotted line, mean of the four dry months; full line, mean of the eight rainy months.

After the transfer of the property to the United States, an interregnum seems to have occurred in some of the meteorological records; but they were resumed early in 1906 by the establishment of two stations, one at Ancon near Panama and the other at Isle Naos in Panama Bay. The following figures give a summary of the results as to temperature and barometric pressure, the latter reduced to sea level. They are in good accord with the earlier determinations given above.

The delicate seismographs established by the French Company at Ancon indicated earth tremors on January 31, February 2, 3, and 7, and May 22, 1906, but they were too slight to be perceived by the observer at Isle Naos, who was instructed to report any earthquake. The disastrous series of shocks at San Francisco in April made no record at Ancon; neither did those at Valparaiso, in August.

METEOROLOGICAL RECORD, 1906

Month	Temperature, Fah.			Pressure, inches			Remarks
	Highest	Lowest	Mean	Highest	Lowest	Mean	
ANCON, CANAL ZONE							
January	93	69	81.0	29.94	29.79	29.84	First 14 days missing.
February	95	69	81.1	30.02	29.78	29.90	
March	95	67	82.6	29 98	29.77	29.88	
April	96	70	82.6	29.92	29.77	29.85	
May	93	73	81.9	29.88	29.77	29.84	
June	91	72	80.3	29.92	29.79	29.85	
July	92	71	80.2	29.90	29.76	29.83	
August	94	71	80.2	29.94	29.76	29.84	
September	92	73	81.0	29.90	29.78	29 84	
October	92	68	79.5	29.88	29.78	29.86	
November	92	67	79.4	29.93	29.74	29.84	
December	92	69	79.6	30.00	29.76	29.88	
ISLE NAOS, CANAL ZONE							
January	95	71	81.3	29.94	29.80	29.86	
February	97	69	81.4	30.03	29.78	29.90	
March	96	69	81.6	29.98	29.78	29.89	
April	94	71	82.2	29.93	29.78	29.86	
May	93	72	81.8	29.88	29.77	29.84	
June	89	70	79.9	29.92	29.79	29.85	
July	92	71	79.7	29.91	29.77	29.83	
August	91	71	80.2	29.94	29 75	29.84	
September	92	73	81.4	29.89	29.80	29.84	
October	92	71	80.2	29.94	29.78	29.85	
November	96	70	79.8	29.93	29.74	29.83	
December	90	70	79.1	29 99	29.76	29.88	

Winds of the Isthmus.—The prevailing directions of the wind have been stated above, and illustrated by the wind rose shown on Figure I. Its velocity was observed at Colon during seven months, from October, 1898, to May, 1899, by the United States Weather Bureau, using a Robinson anemometer, 47 feet above ground.

These velocity observations are specially valuable, as they constitute the only direct measurements ever reported on the Isthmus.

They show during the whole period a great uniformity from day to day and from month to month, the wind increasing gently from about six miles per hour at midnight to about eight and a half miles at two or three o'clock in the afternoon, and then subsiding gradually. The strongest winds came from the Caribbean Sea, usually attaining a velocity of about 20 miles per hour, and on one occasion a velocity of 24 miles.

TABLE 15.—SUMMARY OF WIND AT COLON

Month	Total	Mean velocity	Strongest wind	Estimated direction
	Miles	*Miles*	*Miles*	°
October, 1898	4123	5.5	20 w.	s. 25 e.
November, 1898	3907	5.4	20 nw.	s. 55 e.
December, 1898	5276	7.1	20 ne.	n. 39 e.
January, 1899	4946	6.6	16 ne.	n. 33 e.
February, 1899	4931	7.3	24 nw.	n. 19 e.
March, 1899	5765	7.7	20 ne.	n. 34 e.
May, 1899*	3386	7.1	20 nw.	n. 26 e.

*Eleven days missing.

Isthmian rainfall.—As is well known, there is a sharp division between the rainy and dry seasons; the respective volumes are shown in Table 16, which is a summary of the monthly observations of the officers of the Canal Company and of the Panama Railroad from the earliest dates up to the transfer of the property at the end of April, 1904. Figures in brackets denote the number of years covered by the records.

It is evident from Table 16 that an annual rainfall of about 140 inches may be expected on the Atlantic coast, about 93 inches in the interior, and about 60 inches near the shores of the Pacific. There is a well-defined dry season beginning in December and including the months of January, February, March, and part of April, a period during which the sun is returning northward from his southern journey to the Tropic of Capricorn, and the locus of heavy rainfall has been transferred southward from the Isthmus. This comparative exemption from rain is characteristic of the interior and of the Pacific coast, but somewhat less so of the region bordering the

Caribbean Sea. Clearly it is an important advantage to be able to depend upon having several consecutive dry months in which to prosecute the laying of concrete and other difficult work during the construction of the canal.

TABLE 16.—CONSOLIDATED RECORDS OF RAINFALL IN INCHES

Month	Atlantic		Interior Stations					Pacific Coast			
	Colon	Bohio	Alhajuela	Gamboa	Gorgona	Bas Obispo	Culebra	Panama	Taboga	Isle Naos	La Boca
No. of years	(33)	(7)	(4)	(21)	(3)	(10)	(5)	(4)	(7)	(3)	(5)
January	4.0	9.0	1.3	2.4	3.3	1.8	0.9	0.7	0.5	0.2	2.1
February	1.4	1.8	0.3	0.7	0.6	0.4	0.2	0.7	0.1	0.0	0.1
March	1.6	2.3	0.7	0.9	1.2	0.8	0.3	1.6	0.4	0 0	1.9
April	4.2	5.3	4.9	3.5	2.4	2.7	2.0	2.8	1.7	0.8	4.0
May	12.1	13.3	11,7	10.9	11.6	10.9	12.0	7.6	4.8	6.3	9.2
June	13.4	12.6	12.3	9.6	9.3	11.7	10.2	7.9	5.5	8.2	7.1
July	16.7	17.1	14.7	10.3	13.3	8.8	7.6	7 6	4.3	6.2	9.5
August	15.1	19.2	12.9	12.7	14.2	9.8	8.9	6.8	4.8	7.1	7.2
September	12.6	16.6	11.8	10.9	13.5	12.2	9.1	7.5	7.4	7.3	6.7
October	14.0	18.0	14.9	13.1	11.2	10.5	11.7	9.5	6.6	7.3	9.9
November	20.9	20.3	16.1	12.2	10.4	10.6	11.3	11.6	6.3	4.1	10.1
December	12.3	10.6	7.5	7.0	5.5	9.1	11.2	2.8	3.2	6.6	5.6
Year	128.3	146.1	109.1	94.2	96.4	89.3	85.3	66.8	45.5	54.0	73.4

To aid in estimating the number of rainy days probable in each month, a table giving a complete record for a few years, with their averages, seems to be preferable to one presenting simply averages for longer periods, since it reveals the annual variations. Such a table is the following, covering about eight years at stations where most work will be required. Each day in which rain fell is included. It would appear that the rainfall at Bohio is not only larger in volume but also more frequent than at any other point of the canal line. Further in the interior, where are found the heaviest excavations, a safe monthly estimate would seem to be one week of rainy days and half an inch of rain in the dry season, and three weeks and twelve inches in the rainy season; but it must not be forgotten that on many of these days very little rain falls.

Table 17.—Number of Rainy Days per Month

Month	Colon								
	1899	1900	1901	1902	1903	1904	1905	1906	Means
January	19	11	13	19	9	17	18	16	15
February	12	4	4	5	5	7	8	11	7
March	4	5	6	9	12	7	8	10	8
April	3	4	5	14	11	17	11	12	10
May	17	17	15	20	20	13	27	25	19
June	18	22	17	17	16	17	25	25	20
July	25	23	22	19	18	23	24	29	23
August	21	24	25	13	23	18	23	28	22
September	20	18	21	20	23	18	22	25	21
October	15	23	26	20	18	8	23	20	19
November	15	25	28	23	26	19	25	24	23
December	13	14	23	15	25	15	18	23	18
Year	182	190	205	194	206	179	232	248	205
Bohio									
January	23	17	11	24	10	26	13	16	18
February	18	5	8	3	4	11	13	16	10
March	13	8	11	5	10	16	7	13	10
April	7	6	11	14	10	20	8	14	11
May	17	27	28	(23)	20	29	31	19	24
June	26	27	22	20	19	23	26	26	24
July	25	31	30	20	21	29	24	29	26
August	30	29	29	21	27	22	28	24	26
September	25	28	27	20	26	25	20	25	25
October	21	30	29	24	28	21	23	20	26
November	19	28	30	21	30	23	22	26	25
December	20	20	22	16	30	17	20	26	21
Year	244	256	258	188	235	262	235	254	246
Alhajuela									
January	..	8	5	7	4	12	8	4	7
February	..	1	1	2	2	2	2	7	2
March	..	1	3	3	3	5	4	4	3
April	..	9	5	16	3	10	7	10	9
May	..	18	25	22	22	..	25	14	21
June	..	24	22	27	24	14	17	23	22
July	20	26	21	23	29	19	20	28	23
August	21	22	25	20	27	14	27	29	23
September	20	19	23	18	18	21	18	23	20
October	21	20	26	26	23	16	21	17	21
November	21	20	27	24	27	17	16	24	22
December	11	10	16	12	25	8	15	18	14
Year	..	178	199	200	207	....	180	201	187

TABLE 17.—(*Continued*)—NUMBER OF RAINY DAYS PER MONTH

Month	Gamboa								
	1899	1900	1901	1902	1903	1904	1905	1906	Means
January	13	7	5	17	6	16	18	12	11
February	8	2	2	3	2	2	4	10	4
March	7	2	1	13	3	10	4	3	5
April	6	9	5	22	6	20	10	12	11
May	11	18	20	(18)	23	21	27	17	20
June	23	23	21	16	19	23	19	21	22
July	19	22	21	20	24	25	22	29	23
August	21	21	21	19	26	18	23	27	22
September	18	15	16	21	23	21	21	21	20
October	14	24	25	25	22	17	24	18	21
November	16	24	27	26	25	18	23	29	24
December	10	8	16	10	23	10	19	19	14
Year	166	175	180	210	204	201	212	218	197
	La Boca								
January	..	2	6	8	5	9	0	2	5
February	..	0	1	1	0	3	0	2	1
March	..	0	4	4	1	10	2	1	3
April	..	5	7	6	5	13	11	10	8
May	..	6	14	12	18	13	14	20	14
June	..	17	18	7	9	12	16	18	14
July	..	9	17	8	24	11	10	17	14
August	..	10	16	21	21	10	17	19	16
September	20	..	19	14	15	10	12	20	16
October	18	..	22	20	21	12	22	14	18
November	16	..	19	17	20	7	19	21	17
December	6	..	11	7	19	4	15	20	12
Year	109		154	125	158	114	138	164	138

Table 17 is brought up to date, including monthly means. Rainfall has so important bearings upon the work of construction that it seems desirable to introduce the records in inches kept since the transfer at some important stations. During 1904 such records were continued as under the French administration; but since the organization of the special Bureau under Mr. Arango they have been considerably extended. The station at Colon was soon shifted to Cristobal in the Canal Zone, but the change in location was so slight that the records are interchangeable. By comparing the following figures, month by month, with those in Table 16 the deviation from the normal average can be noted. The seasons have been exceptionally dry, and the result upon the flow of the Chagres is well marked, as will appear in Tables 21 and 23.

ISTHMIAN RAINFALL IN INCHES SINCE TRANSFER

Month	Cristo-bal	Gatun	Bohio	Gam-boa	Alha-juela	Rio Grande	La Boca	Remarxs
1904								
January	7.04	....	6.88	3.35	2.99	....	2 60	
February	0.47	....	3 43	0 24	0.75	....	0.35	
March	1.65	....	3 15	1.93	0 59	....	4.99	
April	11.45	....	13 70	12 01	6 96	....	7.75	
May	11.06	....	12 24	6.71	11.30	....	6.06	
June	15.83	....	8 92	9.71	18.69	....	5.70	
July	13.82	....	9 54	5.01	14.49	....	5.04	
August	11.14	....	8 55	7.01	7.44	....	4.11	
September	13.90	....	12.70	12 43	14 61	....	7 61	
October	6.14	....	9.21	9.51	8 38	....	11.93	
November	29.49	....	13.02	12 01	14 32	....	4.25	
December	4.91	....	5.43	4.54	3.10	....	2.03	
Year	126.90	....	106.77	84.46	92.32	....	62.42	
1905								
January	8.42	8.63	7.93	8.42	2.15	3 80	0.00	
February	1.13	1.99	0.96	0.05	0.09	0.00	0.00	
March	0.62	0.28	0.43	0.41	1.65	0.00	0.43	
April	2.28	1 75	0.75	2.95	1.47	4.00	3.14	
May	22 96	28 81	18.21	10.72	18.06	18.15	3 16	
June	8.10	10.46	7.71	8.59	6 84	10.00	11.63	
July	9.07	13.10	5.42	5.77	7.10	11.20	5.74	
August	15 11	24.12	15 75	11.58	13 24	11.55	......	
September	6 80	10.33	11 22	6 67	7.70	13 85	6 40	
October	13 45	20 70	14 90	14 85	10 88	14 75	7.37	
November	17 92	16 89	13.01	5 49	4.14	4 43	6 67	
December	9.50	11.89	6.43	6.68	5.54	4.66	4.90	
Year	115.36	148.95	102.72	82.16	78.81	96.49	....	
1906								
January	1.47	1.42	0.88	1.37	0.34	0.65	0.68	
February	1.14	1.34	1.94	0 47	0.18	0 28	0.72	
March	1.42	2.37	0.88	0.16	0 28	0.47	0.01	
April	4.23	8 23	5.45	6.44	4 23	4 14	7 16	
May	10.07	12.02	12.09	6 22	9 67	5 20	8 96	
June	14.09	....	11 74	8 04	11 38	6.64	10 48	
July	19.23	....	17.76	17 81	19 17	14 00	7 82	
August	18.31	....	9.02	11 33	26.10	12 61	7.53	
September	12.48	15.02	13 43	9 42	10.75	5 14	3 86	
October	13.34	17 72	9.91	8.98	8.26	7.01	3 37	
November	26.64	24 54	16.99	15 92	21.38	15 59	14.43	
December	15.64	18.69	14.00	11.68	10.80	7.97	5.44	
Year	138.06	....	114.09	97.84	122.54	79.70	70.46	

THE HEALTH OF THE ISTHMUS

The health question, during construction, is one of the important elements of the canal problem. While no one will claim that the climate of the Isthmus is salubrious, it is certain that much wild exaggeration has been circulated, in great part founded on the experience of ill-acclimated laborers on the railroad or canal,

The health statistics during the construction of the Panama Railroad have never been made public, but are well known to have been appalling. At that date it was not understood that natives of the temperate regions cannot safely perform arduous manual labor under exposure to a tropical sun, and that dependence for such work

TABLE 18.—OFFICIAL HEALTH STATISTICS UNDER FRENCH CONTROL

Years	Effective force employed	Percentage of disease			Percentage of mortality		
		Diseases of Europe	Diseases due to climate	Total	Diseases of Europe	Diseases of climate	Total
Old company:							
1881	928	21.02	42.03	63.04	1.94	4.74	6.68
1882	1,910	18.85	47.64	66.49	3.21	4.39	6.60
1883	6,287	23.24	42.62	65.86	3.20	4.46	6.66
1884	17,615	27.58	36.95	64.57	2.58	4.08	6.66
1885	15,215	11.93	49.14	61.07	1.73	3.79	5.52
1886	14,935	14.01	43.88	57.89	1.67	3.43	5.10
1887	16,217	21.83	39.25	61.07	3.22	3.99	6.21
1888	13,725	12.17	40.46	52.63	1.81	2.54	4.35
Mean	10,854	18.83	42.75	62.58	3.05	3.92	5.97
Receiver:							
1889	1,938	....	....	47.06	2.58	2.11	4.69
1890	913	....	....	47.53	2.07	1.21	3.28
1891	862	....	....	49.07	2.79	1.50	4.29
1892	796	....	....	48.49	1.88	0.88	2.76
1893	717	....	....	49.09	1.82	0.83	2.65
1894	805	....	....	51.80	1.25	0.86	2.11
Mean	1,005	....	....	48.84	2.07	1.23	3.30
New Company:							
1895	1,225	....	....	49.95	2.05	0.89	2.94
1896	3,715	....	....	39.91	2.08	0.84	2.92
1897	3,980	....	....	51.85	1.99	1.00	2.99
1898	3,400	28.26	13.65	41.91	1.76	0.27	2.03
1899	2,500	19.76	5.84	25.60	2.24	0.12	2.36
1900	2,000	17.05	8.50	25.55	3.00	0.25	3.25
1901	2,000	18.60	6.85	25.45	1.55	0.20	1.75
1902	1,450	....	....	....	....	....	2.28
1903	940	....	....	....	....	....	3.51
1904	822	....	....	....	....	....	1.10
Mean	2,203	20.92	8.71	37.17	2.10	0.51	2.51

must be placed upon the negroes of the West Indies. White men can supervise, but must not attempt more. Fortunately the health records during the canal operations, and especially those during the operations of the New Company, which should furnish the best guide in view of the great changes in the physical condition of the region, have been preserved, and are shown in Table 18, contributed by Dr. Lacroisade, for many years the medical director of the Company hospital near Panama. He is thoroughly familiar with the Isthmian conditions, and the following historical notes are a translation from a letter written by him on March 9, 1902, and published in *The Medical News,* vol. 80, p. 707, New York, 1902. His views on this important subject are entitled to the highest confidence. He attributes the marked improvement, shown in Table 18, to the better accommodations of the laborers, to better drainage, and especially to the fact that the excavations have reached a level below the poisonous emanations of decaying organic matter. The period of serious sickness incident to excavation in tropical regions, has apparently already been passed at Panama. It is interesting to note that whereas the percentages of disease and of mortality for general ailments have remained sensibly unchanged during three successive epochs, they have fallen enormously in the later years for diseases due to the local climate.

1898.—Among the employees of the company there was no sickness of an epidemic character; the sanitary conditions were satisfactory.

On the Isthmus generally, a light epidemic of influenza prevailed during the months of January and February, but no yellow fever or other sickness of an epidemic form appeared.

1899.—Among the employees of the company there was a single case of yellow fever, contracted at La Boca in November, by a Frenchman recently arrived and employed on the harbor works. He recovered. There was no other sickness of an epidemic form among the employees of the company, and the sanitary condition was satisfactory.

In the City of Panama, between May and the middle of December, there were about 139 cases of yellow fever. Its victims were chiefly foreign sailors arriving in the bay and Colombian soldiers from the interior.

In June and July a rather severe epidemic of influenza occurred. In September a short epidemic of measles caused some deaths. The City of Colon appeared to be proof against yellow fever.

1900.—Among the employees of the company a single case of yellow fever occurred, terminating in recovery, and there was no other sickness of an epidemic form. The sanitary condition was satisfactory, notwithstanding the rather high death rate caused by a larger number than usual of deaths from chronic diseases of a general type.

On the Isthmus, generally, yellow fever, which had disappeared after the middle of December, returned in March. Between that date and September 10, about 138 cases occurred in Panama, of which 128 were among the Colombian soldiers from the interior. There was no other sickness of an epidemic form. The City of Colon escaped yellow fever.

1901.—No epidemic appeared among the employees of the company, and the sanitary condition was very satisfactory.

On the Isthmus, generally, yellow fever, of which no case had been reported since September 10, 1900, was again imported in January, 1901, by a priest and a sister of charity coming from Buenaventura. It was communicated to a sister of the orphan asylum of the central hospital and then to the superior. The latter alone recovered. These four were the only cases in January, 1901; and since then up to the present month (March, 1902) there has been no return of the disease.

In April, 1901, a serious epidemic of smallpox appeared in Panama and still continues. The employees of the company have suffered very little, a result which should be attributed to the numerous vaccinations which have been made.

The City of Colon appears always to escape these epidemics.

General Conclusions.—Considering the average figures for the last four years, I find that with a personnel of 2275 the percentage of disease has been 29.65, and the mortality 2.35 per cent. These figures do not exceed those on large works in any country.

It should, however, be added that this personnel has been long on the Isthmus, and is well acclimated; I may even say extremely so, since 91 per cent. of the total death rate is due to chronic organic diseases common to all countries, leaving only 9 per cent. of it chargeable to the diseases of the local climate.

The classified employees, which constitute about 8 per cent. of the entire force, are represented in the total death rate by 5.70 per cent., while the laborers are represented by 94.30 per cent. The mortality in the latter class is therefore the greater.

Among infectious diseases on the Isthmus yellow fever is undoubtedly the most to be feared by unacclimated persons of the white race. During the two recent epidemics of yellow fever—the first from May to December 15, 1899, and the second from March to September 10, 1900—only two cases appeared among the personnel of the company. Both were French, one a workman on the wharf at La Boca who had been only a few days in the country, and the other the head nurse of the company's hospital who had held this position for two years. To these should be added the superior of the sisters at the hospital, attacked in January, 1901, after three or four months of residence, one of the four solitary cases of this month just mentioned. These three cases recovered. I attribute the last two cases to infection proceeding from the foreign hospital, which received a large number of the 261 cases occurring in the different epidemics and which, by its too close proximity, is a menace to the hospital of the Company. The latter offers satisfactory sanitary conditions.

I have mentioned in former reports the disappearance of yellow fever from the Isthmus from the year 1892 to the year 1897. This would lead to the belief that the disease is in no wise necessarily endemic. In 1897, indeed, between the beginning of March and the beginning of August there were about 70 cases, as well at Panama as on a portion of the line of the canal, but no case occurred at Colon.

I will remark that the City of Colon, which up to about the years 1891-92, was a terrain than which nothing could be better for yellow fever—reputed more dangerous than the City of Panama—has since that time remained free from any infectious disease and has escaped the yellow fever epidemics of 1897, 1899, and 1900. This is evidently due to the sanitary works which have been executed, the filling up of the many little swamps and the cleaning of streets which before were veritable sewers. By these improvements the City of Colon has been considerably freed from the swarms of mosquitoes which rendered life insupportable.

Might not a like result be secured for the City of Panama (1) by a good supply of pure water, (2) by drains to conduct sewerage to the sea, to which its situation and conformation are easily adapted, and (3) by watering the streets daily in the dry season, and by cleaning them daily throughout the entire year. Now they are in a repulsive condition of filth. These three improvements, which I consider fundamental and essential, are now wholly neglected.

There should also be instituted an effective quarantine service for vessels arriving in the harbor, for beyond all doubt the epidemics of 1897, 1899, and 1900, and the few cases which occurred in January, 1901, were due to importations, in one instance from the Atlantic and in three instances from the Pacific.

I do not expect by these measures to remove completely from Panama its character as a terrain favorable for the propagation of yellow fever; but certainly, if thoroughly applied, they would exclude some epidemics and render a residence on the Isthmus less dangerous for unacclimated persons of the white race.

The important works executed from one end to the other of the line of the canal have also done much to improve the sanitary conditions existing on the Isthmus.

The following figures communicated by Colonel William C. Gorgas, Chief Sanitary Officer of the Canal Zone, furnish official mortuary statistics, not only respecting the employees working on the canal and railroad, but also of the entire population of the Canal Zone and of the cities of Colon and of Panama since the property passed under the control of the United States. For May, 1906, and later months, the latter figures include employees who died within the territorial limits of the Zone.

That the advent upon the Isthmus of large numbers of unacclimated persons should increase the death rate was inevitable, but

OFFICIAL HEALTH STATISTICS UNDER UNITED STATES CONTROL

Month	Employees of Canal and Railroad			Zone, Panama and Colon		
	Effective Force	Deaths	Annual Average per 1000	Population	Deaths	Annual Average per 1000
1904						
May	4,447	2	5.39	....	....	....
June	4,782	2	5.01	....	....	....
July	5,762	3	6.24	....	....	....
August	6,029	7	14.00	....	....	....
September	6,709	8	14.33	....	....	....
October	6,499	11	20.30	....	....	....
November	7,460	9	14.40	....	....	....
December	8,022	13	19.50	....	....	....
1905						
January	10,126	13	15.40	38,688	143	43.77
February	11,101	13	14.05	42,623	143	40.20
March	12,710	11	10.38	39,204	145	44.61
April	13,143	12	10.95	39,684	165	49.88
May	14,406	20	16.66	41,000	186	54.43
June	17,517	24	16.32	41,984	223	65.04
July	17,116	45	31.54	41,084	237	69.22
August	19,226	32	19.97	43,055	233	64.95
September	20,624	55	32.00	41,084	214	62.50
October	22,281	61	32.85	41,084	238	69.51
November	20,470	65	38.10	41,589	235	67.80
December	19,417	74	45.73	42,843	231	65.17
1906						
January	22,000	74	40.36	46,249	178	46.18
February	23,135	56	29.09	49,951	176	42.24
March	25,002	78	37.44	51,577	183	42.57
April	27,219	68	30.00	53,671	157	34.91
May	26,136	54	24.79	60,000	263	52.60
June	28,010	97	41.55	60,459	317	62.87
July	28,041	151	64.71	74,777	422	67.72
August	29,555	153	62.12	75,978	406	64.12
September	28,264	135	57.34	76,959	350	54.54
October	25,445	99	46.68	78,090	302	46.40
November	25,872	66	30.61	80,881	241	35.76
December	29,331	74	30,27	83,540	273	39.21

these figures demonstrate that the sagacious and energetic measures adopted by Colonel Gorgas have kept it within limits not unusual in more temperate climates on works of this character.

The following letter from Colonel Gorgas, dated September 12, 1906, expresses in a few words the conclusions resulting from his experience of two and a half years upon the Isthmus, joined to that gained in his previous well-known sanitary work in tropical regions. In reference to his remarks about the French statistics, he writes in a subsequent letter: "From what I know I think that the records under the Receiver and the New French Company represent the true state of affairs. I had in mind altogether the old Company."

"I am sorry that our sick lists for our first year could not be more complete, but those that we sent you are the best that we can furnish. I would like to call your attention, however, to one thing that you have overlooked in your quotations of statistics from the Isthmus; that is, that the French statistics apply practically to Ancon Hospital only. They had no means of knowing with any accuracy the number of deaths that occurred along the line among their employees. The old French Company charged the contractors a dollar a day for their sick employees, and of course the tendency was for the contractor to discharge the man when he got sick, rather than to pay for him in hospital. I feel confident, therefore, that the French statistics represent a very small part of their mortality or morbidity, and are of very little value as a standard of comparison. Dr. Lacroisade is of the opinion that they got a large part of their sick into Ancon Hospital. Mr. Mallet, the British Consul, is equally confident that they got a very small part. All that I can find out on the subject leads me to agree with Mr. Mallet rather than Dr. Lacroisade. The French never at any one time, the Doctor tells me, had more than 700 patients in Ancon, and this number only on one occasion. As they averaged for nearly three years in the neighborhood of 17,000 men, it is of course impossible that 700 could have been their maximum number of patients from such a body of men.

"Our most important accomplishment, so far, from the point of view of the construction of the Canal is the eradication of yellow fever. We have had no case of yellow fever in the city of Panama since the 11th of last November, and only one case on the Isthmus during the year 1906. If we were doing this work under the conditions and with the knowledge we had twenty-five years ago, we would be losing from yellow fever at the rate of 40 men per month, and this loss would fall entirely among the Americans, for we twenty-five years ago could probably have done no better in sanitary directions than the French did. The French at that time, with 2,500 white employees, were losing from yellow fever at the rate of 20 per month. We at the present time have about five thousand white employees.

"Another important result of our sanitary work is the demonstration of the fact that our white employees can live on the Isthmus and maintain about the same condition of health, as they do in an average healthy locality in the United States. You will see that our average death rate among the whites, from disease, for the last six months, has been small, and if we considered our American population alone it would be smaller. About a thousand of our whites are day laborers, Spaniards, Italians, and other nationalities, who have a higher death rate than our American employees.

"The death rate among the negroes is large, increased for the last six months by the prevalence of an epidemic of pneumonia, which has just begun to subside. But for one reason and another they have not the stamina that the whites have and suffer in all directions more than do the whites. I hope, however, that in the course of time, we will be able to greatly improve their condition. I would be willing to guarantee that within six months we could reduce the death rate among the negroes to the same figures as at present obtain among the whites if we could enlist them, discipline, and care for them as we do our negro regiments in the United States. We are endeavoring to approximate this condition of affairs, and I believe that every month we will be able to make a better and better showing in these respects. Last month among our four thousand white Americans we did not have a single death from disease."

In connection with the subject of the health of the laborers, the following views of Mr. Stevens upon their relative efficiency are pertinent. They are quoted from his last annual report:

"Our labor consists almost entirely of West Indian negroes, and their efficiency is very low, although we have a few of this class who are fairly steady workers—by this is meant that they average to work all the time, but the great body of them do not.

"The majority work just long enough to get money to supply their actual bodily necessities, with the result that while we are quartering and caring for twenty-odd thousand of these people, our daily effective force is many thousands less.

"Preliminary steps have been taken toward looking to the securing of large numbers of Spanish laborers direct from the Northwestern Provinces of Spain, and also for the securing of a trial shipment of Cantonese Chinese, as it is believed that the introduction of laborers of different nationalities will be beneficial, and it is hoped that in the early part of the succeeding year the labor situation will be greatly improved. . . . Since the decision of the type of canal has been made, 5,000 or 6,000 more could have been used than have been available, which has tended to somewhat delay the progress of the work."

CHAPTER V

THE CHAGRES RIVER

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 Gatun to near Gamboa, a total distance of about 25 miles. Below Bohio a separate channel was projected, but at so short a distance as to require levees for protection in times of flood. Above Bohio the two formed 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 fluviographs, 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 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 the 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 bi-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 five 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 sub-basin 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 or more inches 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 sub-basin 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.

The problem before the engineers of the New Company was to complete a canal already largely constructed as far as Bohio. The district below that point therefore received less attention. The river receives two important tributaries in this part of its course, the Trinidad on the left bank draining a region about 320 square miles in extent, and the Gatuncillo on the right bank with a basin of 160 square miles. The total area of the basin of the Chagres above Gatun is thus about 1200 square miles, that above Bohio being about 700 square miles. The respective annual discharges are about 8200 and 4800 cubic feet per second, the extreme low water volumes during the three dry months being about 1225 and 742 cubic feet, as will appear further on.

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 1899-01 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 method of measurement was the following: "The sample taken was allowed to settle for twenty-four hours, and 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 the 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 this rather crude method gave approximately the specific gravity of the deposits made by the Chagres River, a little computation will show that the average during these four rainy months indicates at Alhajuela 0.015 of one per cent. of the volume of water; at Bohio 0.018 of one per cent.; and at Sabalos station 0.008 of one per cent. That of the Mississippi in floods is 0.088, and of the Ganges 0.098 of one per cent. Thus it appears that the

Chagres carries a relatively small volume of sedimentary matter even in the rainy season, and, what to say the least is surprising, that the larger part of what passes Bohio comes from above Alhajuela—the relative volume of water being 51 per cent. and of sedimentary matter 62 per cent.

The figures as reported by the Commission are presented for comparison in the first half of Table 19, the second half being added to show the corresponding total discharge of the rivers as indicated by the gaugings of the Commission.

Although these data are not reported in a unit permitting an accurate comparison with similar observations on other streams, they

TABLE 19.—SEDIMENTARY MATTER

Month 1900	Solid matter in cubic yards at			Total discharge in acre-feet		
	Alhajuela	Bohio	Sabalos Station	Alhajuela	Bohio	Sabalos Station
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	251,730	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

make it evident that the volume of sedimentary matter which will be carried in suspension to Lake Bohio will have little practical importance. Whatever comes down will be deposited near the entrance where it can easily be removed by dredging. 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 Alhajuela.

The tributary streams below Alhajuela, 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 Alhajuela and Gamboa and seventeen thence to Bohio; and there are about thirty 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 fluviographs established at Gamboa in 1882, at Bohio before 1890, and at Alhajuela in 1899, have furnished a nearly continuous 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.

In extreme low stages the elevation of the water surface at Bohio, some 27 miles above the mouth of the river by the course of the stream, is but very slightly raised above the mean level of the sea. Thus during the month of February, 1906, this height was only 1.51 feet; in March, only 1.12 feet; and in the first 18 days of April, only 0.96 feet. After the latter date some slight variations in the volume of the river rendered its estimation uncertain, but before that period the flow, largely caused by escaping ground water, fell very gradually from about 900 to about 400 cubic feet per second, and permitted a fairly close estimation day by day of any tidal oscillations. They were unmistakeable, and proved to be in February about 2.7 inches, in March, about 2.4 inches, and between April 1 and April 18 about 3.0 inches. The matter is not without importance in its bearing upon possible interference with the indications of the rating table caused by abnormal variations in sea level due to prevailing winds; and for this reason the study has been carried further. Recent observations show that the tides at Colon are of the diurnal or single day type, as are those indicated above for Bohio, their well-known average oscillation being about 1.43 feet, ranging between 2.07 and 0.62 feet. What should be the transmitted influence of such tides upon the twelve means of the bi-hourly fluviograph readings at Bohio during a lunation? The succession day by day of tides varying from spring to neap in range and following

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each other at about an hour's interval should register on these means variations sufficient to indicate the tidal type, but of reduced range by reason of mutual daily interference. The following figures show the result of such a computation during the period in question, which covered nearly three lunations. They register in feet for each month (in 1906) the average heights above mean sea level at the hours indicated.

TIDAL OSCILLATION AT BOHIO

Hours	February	March	April	Grand Mean	Remarks
Midnt.	1.45	....	....	....	Full moon, in local time:
2 a. m.	1.45	1.09	1.00	1.180	Feb. 9, at 2h. 27m. a. m.
4 a. m.	1.46	1.11	1.02	1.197	March 10, at 2h. 58m. p. m.
6 a. m.	1.50	1.15	1.02	1.223	April 9, at 0h. 53m. a. m.
8 a. m.	1.54	1.19	1.02	1.250	
10 a. m.	1.59	1.20	1.00	1.263	
Noon	1.61	1.17	0.96	1.247	
2 p. m.	1.57	1.16	0.92	1.217	
4 p. m.	1.55	1.13	0.91	1.197	
6 p. m.	1.49	1.10	0.90	1.163	
8 p. m.	1.46	1.07	0.90	1.143	
10 p. m.	1.46	1.06	0.93	1.150	
Midnt.	1.44	1.06	0.98	1.160	
Means	1.51	1.12	0.96	1.199	

If these three monthly records be reduced to the same absolute sea level and platted one after the other in a continuous curve, it will present the appearance of a wavy line representing three lunations, and showing three maxima and four minima points well marked. The intervals between the former are about 22 and 21 hours, and between the latter about 22, 24, and 22 hours respectively, as nearly as the turning points can be estimated. The corresponding tidal ranges are 1.92, 2.04, 1.80 and 1.56 inches, which are less than the above more precise determinations, as was to be expected. The grand mean shows a range of 1.3 inches, still further reduced by interference. The monthly means of course do not fix the days on which occurred the turning points of the tidal curves, but the daily records suggest a good accordance with what should be expected from the dates of full moon given in the table.[1]

[1]It is not without interest to compare these tides at Bohio with those of

If these ordinary tidal variations of about a foot and a half are distinctly felt at Bohio, it is certain that considerable abnormal changes in level due to prevailing winds must powerfully affect the water level there in low stages of the river. It is this fact that gives practical importance to these researches, as will appear further on.

Ascending the river from Bohio 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 occurred at Bohio where a piling up of water is needful to carry the volume to the sea, the bed being nearly horizontal below that point. The oscillation there was 39.4 feet, becoming at Gamboa about 37.7 feet, while at Alhajuela, although the only authentic records available are those of the great flood of 1906, they demonstrate that it could hardly have exceeded 27 or 28 feet. Relations like these can be better presented graphically than by tables, and attention is invited to Figure VI for details.

As in all rivers, there are considerable variations in the dimensions of the waterway at different localities near each other; but Table 20, giving those at the three gauging stations, may be considered to represent the channel fairly well under normal conditions in the neighboring parts of the valley. In it "height" refers to ele-

record upon the Mississippi. The tides of the Gulf of Mexico there are also of the diurnal or single day type, having at the mouth of the river a normal oscillation of 1.2 feet, with a recorded abnormal change in Gulf level, corrected for tidal oscillation, of at least 3 feet. At Carrollton, 118 miles above, spring tides show a range of about 3.6 inches and neap tides about 1.2 inches, the retardation being about six hours. Even at the mouth of Red River, 315 miles from the Gulf, observations at the low stage suggest a slight tidal variation but too small to be accurately estimated. There is nothing surprising then in these indications at Bohio.

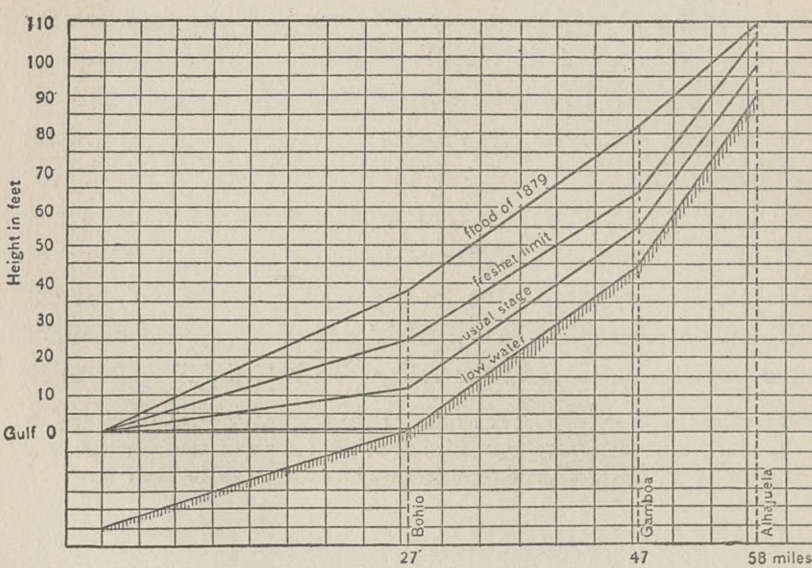
vation above mean tide level, and "velocity" to the maximum rate of flow as measured by surface floats following the thread of the current at the stages indicated.

TABLE 20.—TYPICAL CROSS SECTIONS OF THE CHAGRES

River Stage	Alhajuela, sea 58 miles				Gamboa, sea 47 miles				Bohio, sea 27 miles			
	Height, ft.	Width, ft.	Area, sq. ft.	Veloc., ft. sec.	Height, ft.	Width, ft.	Area, sq. ft.	Veloc., ft. sec.	Height, ft.	Width, ft.	Area, sq. ft.	Veloc., ft. sec.
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	over	bank	14.1	26	288	6,362	7.9
Flood limit	110?	381	5,834	?	83	over	bank	?	39	over	bank	?

The lowest water level of record occurred in April, 1901, being at Alhajuela 28.0 metres (91.86 feet), at Gamboa 13.72 metres (45.0

FIG. VI. CHAGRES RIVER, VERTICAL LONGITUDINAL SECTION



feet), and at Bohio 0.14 metres (0.46 feet) above mean tide. For convenience, the low stage at these three posts has been assumed as

Gamboa Fluviograph, showing H. W. Mark, 1906 (just above lower platform)

28 metres, 14 metres, and 0 metres respectively; the superior limit of usual stages being 30 metres, 17 metres, and 4 metres. It may be remarked here that, as all the records and computations of discharge have been made in metric units, some slight discrepancies may be noted in figures, due to the neglect of small fractions in the transformation into English units.

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 21, which gives the number of times in each month that the river rose above 17 metres (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 metres); 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 metre 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.

In extending this and other tables to include data collected since the transfer of the property to the United States, it has seemed preferable to append them without incorporation in the means;

TABLE 21.—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	0.8	1	4	7.7	3.7
1905	0	0	4.8	8.4	0	0	1.3	0.1	0	0	1.5	0.4	0	0	1.2	3.0
1906	0	0	1.4	1.4	0	0	1.5	0.5	0	0	2.0	0.2	0	0	3.8	6.4

TABLE 21.—*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
1890	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
1904	0	0	6.1	6.7	2	18	13.9	9.7	1	3	10.6	5.0	0	0	5.7	7.0
1905	2	8	12.7	10.7	1	14	15.4	8.6	0	0	4.7	5.8	1	4	11.0	11.6
1906	1	17	15.5	6.2	0	0	7.2	8.0	4	20	13.5	17.8	1	8	12.1	11.3

TABLE 21.—*Continued*

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
1890	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
1904	3	12	12.8	12.4	0	0	9.7	9.5	3	47	18.6	12.0	1	1	10.1	4.5
1905	0	0	6.1	6.7	2	22	15.9	14.8	0	0	9.5	5.5	0	0	7.6	6.7
1906	1	11	11.5	9.4	1	2	10.1	9.0	1	47	22.3	15.9	3	73	35.7	11.7

the original period was sufficiently long to afford normal values and by this arrangement a convenient comparison month by month is rendered easy.

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-metre 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 4 hours, and the 20 miles thence to Bohio in about 6.5 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 24 hours to 48 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 21, 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 approaching a minimum in 1898 and 1899. Data for accurate estimates of discharge do not exist prior to 1890, and therefore this evidence of annual

Year	No. of freshets	Above 17 meters, hours	Local rainfall, inches
1883	21	201	70.5
1884	25	334	87.1
1885	37	437	95.7
1886	43	437	97.8
1887	39+	649+	126.9
1888	29	596	100.3
1890	34	308	95.2
1891	10	116	74.6
1892	24	269	95.3
1893	12	220	107.9
1894	25	263	87.6
1895	7	54	....
1897	14+	151+	102.5
1898	8	51	78.3
1899	8	57	70.5
1900	12	84	74.2
1901	13	107	90.0
1902	5+	33+	59.3+
1903	12	94	97.9
Means	20	235	89.5
1904	13	94	84.3
1905	6	48	82.3
1906	12	178	98

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 shown by the Isthmian Canal Commission of 1899-01; and the rain record at Colon suggests it likewise.

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 21 in 6-year epochs, as is done in Table 22, taking into account the different months. These 6-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

TABLE 22.—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 6 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
Totals	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

approximately one-fifth part should be added when comparing it with other months. This correction has been made in the averages.

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 same conclusion results from a study of the annual discharges, as will appear further on. The investigations of the Isthmian Canal

Commission of 1899-01 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 traversing 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 metres 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 metres 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 metres per second, and C the height of the water level above mean sea level, in metres.

(1) Alhajuela, $Q = -6+52(C-27.5)^2-1.6(C-27.5)^3$
(2) Gamboa,[1] $Q = -24+24(C-13)+18(C-13)^2-0.5(C-13)^3$
(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 by simply increasing the coefficients of the first power of the water-level term in the respective general formulæ. At Gamboa and Bohio the increase was proportional. These special freshet formulæ, thus deduced, are the following, the variables having the same signification as before.

[1] From gaugings at dead low water the discharge at 13.7, 13.8, 13.9, and 14.0 metres is estimated at slightly increased figures; that is, at 10, 12, 15 and 19 cubic metres per second respectively.

In practically applying them, the mode of their framing and the object had in view should be borne in mind. They are based wholly on gaugings made in pronounced freshets, and their object is to make known the *total volume* passing during such exceptional flows, and not the *actual volume* passing at any given instant. They aim to give the mean between the different volumes of the rising and falling river at each stand of the gauge. From these considerations it results (1) that they are not applicable to small oscillations below the normal limit of freshets, but only to such rises as develop excessive slopes of water surface; and (2) that in making use of actual gaugings to assist in determining which formula to use in any doubtful case, the freshet formula should always indicate too small a volume for rapidly rising river and too large a volume for rapidly falling river. Its indications should be compared with the mean between two such gaugings taken at about equal water levels. The cases where such a check is useful correspond to sudden and considerable rises from a quite low stage, but only attaining a height about equal to that assumed as the normal lower limit of freshets. This limit is somewhat arbitrary, and actual gaugings are useful in such cases to determine whether or not the local slopes of the water surface conform to the exceptional or to the ordinary type.

(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 bi-hourly fluviograph 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 bi-hourly 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 bi-hourly fluviograph 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 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

TABLE 23.—DISCHARGE IN CUBIC FEET PER SECOND, UNDER FRENCH CONTROL

AT ALHAJUELA

Month	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	Means
January	2190*	1554	1165	1731	2825	2684	2437	1342	3284	2684	1589	989	4238	1130	3002	2190
February	1095	777	918	1660	1342	1236	1059	918	1236	777	812	671	1271	848	1589	1081
March	918	494	812	1024	777	742	600	424	600	777	530	459	812	494	954	695
April	1024	424	1695	2402	600	918	1271	563	1519	883	565	459	1695	565	2190	1118
May	3249	2649	4203	2331	1059	1483	2543	2507	1872	1589	1342	1554	2119*	1377	....	2134
June	4061	1801	2649	2437	1695	2048	2225	1801	2190	2154	1554	1731	2190	1942	....	2177
July	4097	2861	5651	2719	3390	1801	2225	2861	3143	2225	2190	1978	2119	3108	....	2883
August	4309	2119	4626	3602	2967	2543	2145	3108	3143	3284	2825	2437	2331	3178	....	3044
September	5191	2296	3320	2967	3390	1907	2154	2931	1907	2402	2154	2931	2366	2790	....	2765
October	4909	3390	4521	2896	3567	3638	2048	2931	2649	2649	3214	2755	3214	2755	....	3224
November	3002	5686	5509	3461	4980	2543	2472	3390	3885	2931	2967	4768	3143	4009	....	3832
December	4485	3885	4627	6110	8088	3920	3885	3532	1731	2260	2296	3037	1836	5474	....	3940
Year	3211	2328	3308	2778	2890	2122	2089	2192	2263	2051	1837	1981	2278	2381	....	2424
Three dry	1012	565	1142	1695	906	965	977	635	1118	812	636	530	1259	636	1578	965
Nine rainy	3944	2917	4030	3139	3551	2507	2459	2711	2645	2464	2237	2453	2617	2963	....	2910

AT GAMBOA

Month	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	Means
January	2755*	2048	1519	2296	2708	3532	2225	1760	4309	3496	1695	1024	5227	1625	4132	2757
February	1342	954	1095	2013	1625	1483	1130	1130	1483	954	812	671	1589	918	2402	1307
March	1045	600	989	1236	954	1095	636	494	1024	954	530	459	1024	706	1695	896
April	1059	530	2048	2931	742	1130	1342	671	1836	1059	565	459	1942	706	2861	1325
May	4273	3461	5509	3037	1377	3461	4450	3284	2472	1907	1342	1766	2896*	1519	....	2904
June	5333	2366	3496	3214	2225	3178	4132	2366	2861	2472	1942	2048	2896	2154	....	2906
July	5403	3779	7416	3567	4450	3073	2931	3779	4238	2825	3355	2190	3002	3320	....	3809
August	5686	2790	6075	4732	3885	4061	2331	4097	4132	4238	3567	2861	2790	4344	....	3971
September	6816	3037	4379	3885	4450	3390	2719	3850	2543	3178	3073	3638	2931	4697	....	3756
October	6498	4450	5933	3744	4697	4944	2684	3850	3461	3390	4520	3702	4415	3956	....	4303
November	3956	7487	7240	4556	6534	3532	3249	4450	5192	3744	4061	6746	4732	5721	....	5086
December	5898	5121	6075	8052	10630	3779	5121	4626	2296	2649	2684	3143	2190	7028	....	4949
Year	4172	3052	4314	3605	3773	3055	2750	2864	2987	2572	2345	2391	2969	3058	....	3164
Three dry	1149	695	1377	2060	1107	1236	1036	765	1448	989	636	530	1518	777	2319	1176
Nine rainy	5180	3838	5294	4120	4662	3661	3317	3563	3500	3100	2915	3013	3453	3818	....	3827

TABLE 23.—*Continued.* DISCHARGE IN CUBIC FEET PER SECOND, UNDER FRENCH CONTROL

AT BOHIO

Month	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902	1903	1904	Means
January......	4132*	2684	2331	3532	7063	4556	4732	2048	5651	3850	2119	1483	11231	1625	4944	4132
February.....	1554	1377	1271	2331	1801	1377	1554	1589	1695	1731	1059	989	2084	1024	2331	1585
March........	1271	600	1165	1448	1095	1059	1695	706	1095	989	742	706	1271	636	1413	1009
April.........	1236	600	2366	3426	777	1059	1695	883	2013	1095	706	565	2154	565	3638	1519
May.........	6569	5333	8476	4662	3355	4167	4944	7982	2684	2048	1625	2296	4273*	1519	....	4281
June.........	8193	3214	5439	4944	4273	4309	4203	4203	3355	3143	2861	2790	3178	2543	....	4046
July.........	8300	4803	11407	7628	6216	4591	3143	5121	6569	3956	5615	3178	3037	4026	....	5542
August.......	8759	4521	9359	10772	6498	6922	3496	7275	5298	5721	5262	4309	3390	5474	....	6218
September....	10489	4344	6746	7664	7452	5792	5933	6887	3214	4238	4768	5792	3920	5686	....	5923
October......	9995	6851	9112	8582	9359	6922	6357	7487	5050	4944	6993	6322	5933	5580	....	7106
November....	6075	11513	11125	11443	12714	6075	7593	6957	7840	5296	6605	13244	6675	8335	....	8678
December.....	9076	7876	9359	18541	12573	6957	6039	6816	2861	3602	3744	4591	3002	10489	....	7538
Year.........	6304	4476	6513	7081	6098	4482	4216	4830	3944	3384	3509	3855	4179	3958	....	4798
Three Dry....	1354	859	1601	2402	1224	1165	1377	1059	1601	1272	836	753	1836	742	2461	1371
Nine Rainy...	7954	5682	8150	8641	7723	5588	5160	6086	4725	4089	4400	4889	4960	5031	....	5940

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 including 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 ± 1.0 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±2.0 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 preceding 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 heavier faced 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, fluviograph 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.

In extending the table to include data collected since the work has been conducted by the United States, it has seemed preferable to present them separately, in order to facilitate a comparison month by month with what may properly be regarded as normal conditions. The computations are based on the fluviograph records, following the identical method used heretofore. It is, however, more than probable that the later volumes thus computed at Gamboa

TABLE 23.—*Supplement.* UNITED STATES IN CHARGE

Month	Alhajuela			Gamboa			Bohio		
	1904	1905	1906	1904	1905	1906	1904	1905	1906
January	above	1418	....	3719	1687	1020	above	1987	1215
February		777	....	2162	1032	783		1060	816
March		578	....	1526	844	610		790	611
April		442	....	2575	703	849		682	950
May	1820	1932	....	2275	2183	1608	2871	2847	2077
June	2659	1594	....	3073	2091	1612	4541	2671	2433
July	2677	1248	....	3271	1684	3051	4175	1960	5905
August	1579	2207	....	2142	2613	3823	3001	3623	6086
September	2834	1722	....	3822	2231	3508	6245	3692	5154
October	2031	2688	....	2974	3480	2746	4570	6971	3894
November	4143	2267	3433	4561	2585	5128	7552	4477	8476
December	2350	1265	7283	2711	1835	7386	4043	2839	12406
Year	2319	1512	....	2901	1915	2677	4110	2800	4169
Three dry	1578	599	....	2087	859	747	2461	844	792
Nine rainy	2566	1815	....	3172	2265	3320	4660	3452	5294

were excessive, for they exceeded those measured at Bohio in several months. An examination of the old instrument demonstrated that it was in poor condition, and that the recorded water levels exceeded slightly those shown by the established bench mark. The recorder had failed to make the corresponding corrections. The discovery was made in the summer of 1906, and thorough repairs were at once made. It remained to make the corresponding corrections in the record. An elaborate analysis of the relative volumes

Months	Alhajuela / Bohio in %			Alhajuela / Gamboa in %			Gamboa / Bohio in %			
	Normal	1904	1905	Normal	1904	1905	Normal	1904	1905	1906
Year	55	56	54	79	80	79	68	71	68	64
Three dry	71	65	71	82	76	70	86	85	102	94
Nine rainy	51	54	53	76	80	80	65	68	66	62

carried at Alhajuela, Bohio and Gamboa based on the above well established ratios showed that the two former stations were in good accord, but that they concurred in indicating the same identical excess at Gamboa; it was progressive in character, the correction ratio being 0.9 for the year 1904, and 0.84 for the year 1905. These figures indicate an excess of from three to four inches in the recorded water levels at Gamboa, and the figures in Table 23 (Supplement) have been corrected accordingly. That the results are trustworthy is manifest from the above tabular comparison of resulting ratios.

It is believed that Table 23 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.

Table 22 presents the evidence of a periodical change afforded by a study of the number and duration of the freshets, and it is not without interest to check it by the discharges actually measured at Gamboa in the second and third six-year epochs, and also since the transfer. The volume is lacking for the first six-year epoch. The following figures present this evidence.

PERIODICAL VARIATION IN FLOW

	First Epoch 1883-1888	Second Epoch 1890-1895	Third Epoch 1898-1903	1904	1905	1906
Number of freshets..	34	20	11	13	6	12
Hours above limit....	455	214	93	94	48	178
Local rainfall in inches	102	99	88	84	82	98
Discharge ft.-sec......	....	3662	2720	2901	1915	2677

These records leave no doubt that a minimum epoch is now passing, and that we may expect soon to enter upon a period of increasing rainfall and river discharge. The first French Company apparently labored under conditions differing but little from the probable maximum, and the records of the Panama railroad indicate that it was preceded by a minimum.

THE FLOODS OF THE CHAGRES

Only six 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

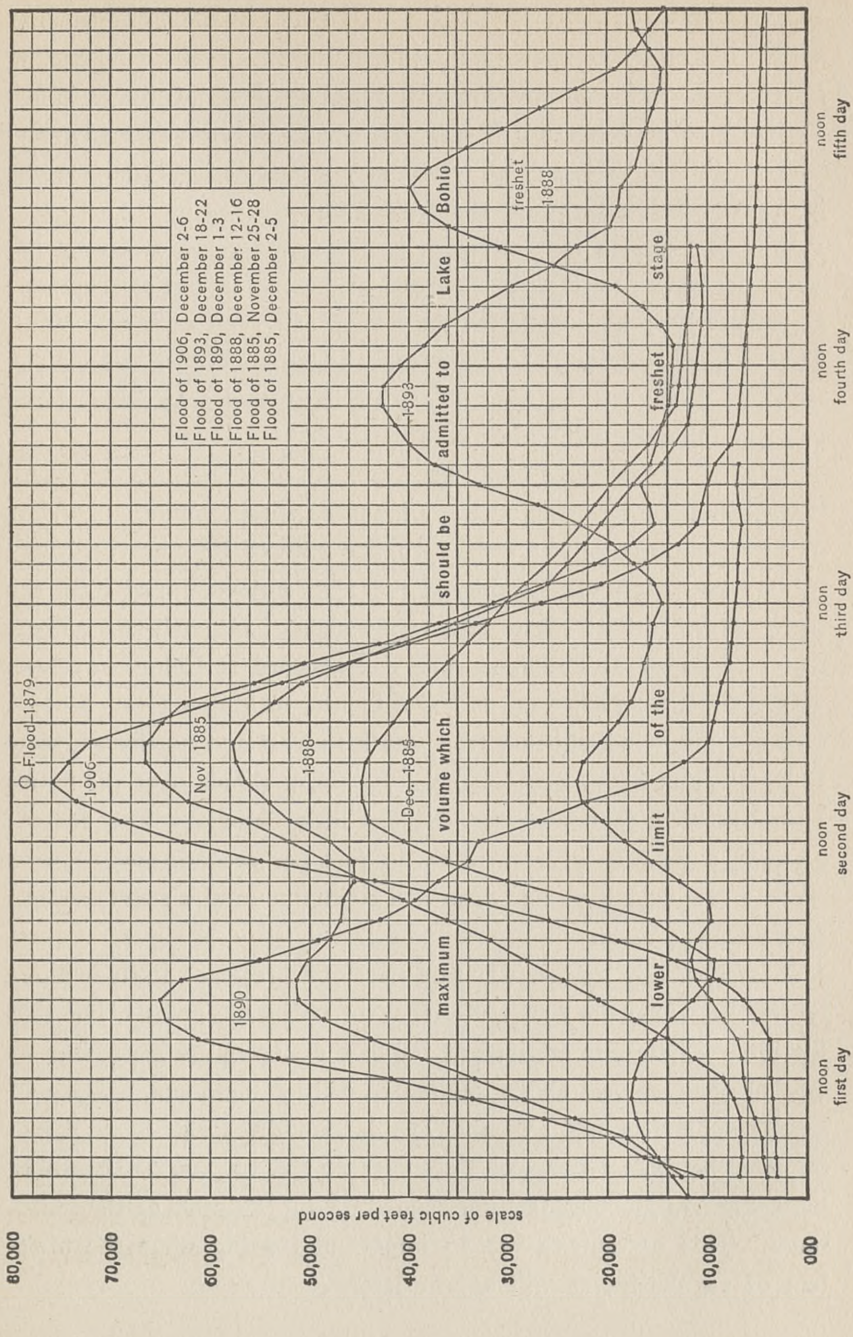


FIG. VII. Bi-hourly discharges of the Chagres River at Gamboa in its great floods.

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 bi-hourly discharges there are shown in Figure VII. The different floods will be treated in turn, beginning with the last but one and following back in order of date.

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.

It is shown by Figure 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 48 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 curve marked 1893 on Figure VII exhibits the discharges deduced from the bi-hourly 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 fluviograph represents the river. The discrepancy is only about 3 per cent., and that on the safe side.

Date 1903	Hours	Height above sea, metres	Discharge in feet seconds			Remarks
			Measured	Tabular	Difference	
Dec. 19	8:15 a. m.	17.32	12,714	13,173	—459	
do	9:00 a. m.	17.52	13,420	14,223	—813	
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	
Dec. 20	8:45 a. m.	17.79	15,857	15,751	+106	
Dec. 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
Dec. 22	11:00 a. m.	17.86	16,387	16,175	+212	
do	3:20 p. m.	17.63	14,409	14,868	—459	
Dec. 23	7:35 a. m.	17.05	11,619	11,760	—141	
do	3:50 p. m.	17.22	12,679	12,643	+36	
Dec. 24	10:40 a. m.	16.67	9,853	9,853	000	
do	3:10 p. m.	16.31	7,805	8,193	—388	
Dec. 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	
Means	....	....	15,446	15,899	—453	

The river in floods receives considerable contributions from the tributaries intermediate between Gamboa and Bohio, 20 miles below. Moreover the low lands 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 48 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 Figure 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 17 hours, and immediately subsided about 21 feet in 23 hours. These figures at Bohio were 19 feet in 31 hours and 11 feet in 14 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 Interoceanic Canals was informed under oath in February, 1902, that a rise "as high as 52 feet in 2 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 48 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. Bi-hourly 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 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 48 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 128 hours. There were other freshets of moderate height but of unusual duration in this month, giving a record of 424 hours above the 10-foot stage, or more than double that of any other month in the 20 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 fluviograph 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 48 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. Bi-hourly 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 24 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 24 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 24 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 24 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 kilometre points 16 and 22 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 36 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 5 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 fluviograph 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 48 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 rise 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 48 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 exceeded any one of later date, even the last, 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 meagre. The water level at Gatun attained a height of 23 feet above mean tide, at Bohio exceeded 39 feet, and at Barbacoas reached 62.3 feet above the same datum. These facts were officially reported on April 29, 1884 by M. Clavenad, Chief Engineer of the 1st and 2d Divisions, which included these localities. 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 were 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 Bohio	39.37	34.68	4.69
Difference	4.59	5.28	0.69

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 reached 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 Bohio 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 Bohio considerable excavations had been made, and if they had tended to lower the water level their effect should have been much more apparent at Bohio, 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 Bohio 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 Bohio 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 Bohio 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 all other known floods. The table gives the extreme heights above mean sea level in metres, and the figures below indicate the calculations to deduce the probable height at Gamboa. The probable levels at Bohio in the flood of 1885 are deduced in a similar manner.

Locality	1879	Nov. 1885	Dec. 1885	1888	1890	1893	Nov. 1906	Dec. 1906
Gamboa	25.10?	23.60	21.35	23.56	23.70	21.72	20.76	24.89
Buena Vista	13.40	.....	.....	12.18	.....	.....	.....	.....
Bohio	12.00	10.30?	8.05?	10.57	9.80	8.70	7.95	11.78

$$23.56 + (12.00 - 10.57) = 24.99$$
$$23.56 + (13.40 - 12.18) = 24.78$$
$$23.70 + (12.00 - 9.80) = 25.90$$
$$21.72 + (12.00 - 8.70) = 25.02$$
$$20.76 + (12.00 - 7.95) = 24.81$$
$$24.89 + (12.00 - 11.78) = 25.11$$

Resulting height......25.10±0.12 metres.

In other words, the extreme height of the flood of 1879 at Gamboa was 36.42 feet above low water, with a probable error of about 5 inches. This would indicate a maximum momentary discharge of about 78,000 cubic feet per second.

Flood of 1906.—When it occurred this second edition was in press, but Mr. Arango very kindly transmitted his data so promptly as to permit their insertion, thus rendering it possible to complete the record for half a century; for as already stated the flood of 1879 was the first of importance after the construction of the Panama Railroad. Records so ample are invaluable in studying the technical details of the canal project, and it is fortunate that the occurrence of a great flood at this late date has permitted American engineers to contribute their quota to the observations amassed under the French direction. When the event occurred Mr. Arango had perfected his arrangements for its measurement, and the river was carefully gauged at all three stations; very fortunately including Alhajuela where observations had been temporarily suspended earlier in the year.

The flood of 1906 is quite similar to that of 1885, being characterized by two distinct rises at nearly the same dates in both years, and not unlike in volume, but differing in that the larger outflow followed instead of preceding as in 1885.

The first and smaller rise was due to heavy rainfall which prevailed over the entire Isthmus on November 15, 16 and 17; but what is very unusual the larger downfall, exceeding four inches at several stations on the 17th, had place on the Pacific side of the divide where it did not contribute to swell the Chagres.

At Alhajuela the rapid rise began at 10 a.m. of the 15th, but was of short duration, the maximum discharge being 43,121 feet-seconds, and the largest average in 24 hours (2 p.m. of 15th to 2 p.m. of 16th) being only 25,463 feet-seconds. At Gamboa these figures were 40,075 and 30,793, the latter occurring on the 16th. At Bohio they were 46,292 and 43,581, the latter between 8 p.m. of 16th and 8 p.m. of 17th. These figures make apparent, what indeed might be inferred from the general distribution of the rainfall, that the lower tributaries contributed largely to this first class freshet. During the 48 hours of largest flow at Alhajuela, from noon of 15th to noon of 17th, the average was 16,426 feet-seconds; at Gamboa it was 25,003 feet-seconds (between 10 p.m. of 15th and 17th); and at Bohio it was 38,738 feet-seconds (between 8 a.m. of 16th and 18th).

The large maximum volume in this rise might suggest that it be classed as a minor flood, but its comparatively short duration, indicated by its relatively small discharge in 48 hours, tends to negative this conclusion. Indeed it will be seen from the computations following Table 26 that the volumes, needful to hold back for regulation, are only about one-third as much as in the flood of 1893, the smallest so rated heretofore. Still, as this large freshet so closely proceded the true flood, it certainly should be considered in connection therewith, as was done with the flood of 1885. Some slight damage resulted; and one of the wooden supports of the gauging cable at Gamboa was carried away by floating débris, preventing the use of the current meter, but direct measurements were made with floats. At Bohio both methods were used. The above figures are derived from the fluviograph records.

The second rise was far more important; indeed it must take rank among the largest floods of the river. About fifteen miles of the main line of the Panama Railroad were submerged from two to ten feet, and water stood on the track at Matachin five feet deep. Two small railroad bridges were carried away, but canal operations suffered only temporary interruptions.

The most definite mode of comparing this flood with that of 1879, which has been adopted as the standard in projecting the works for regulation, is based (1) on the volumes needful to be held back for the protection of the district below Bohio, and (2) for the elimination of objectionable currents near Gamboa where the river joins the route for shipping. As will appear below, those reserves for the former purpose would be about 130,000 acre-feet in 1906 and about 145,000 acre-feet in 1879; and for the latter purpose about 56,000 acre-feet in 1906 to compare with about 62,000 acre-feet in 1879. Manifestly this recent flood, although slightly inferior to the standard, so nearly approached it as to confirm the judgment of the engineers in a most satisfactory manner.

The hydrology of this great flood can hardly be better described than in the following report of Mr. Arango to Mr. Stevens dated December 18, 1906. How it compares with former inundations will appear further on, when considering requirements in detail.

"I beg to submit the following report in connection with one of the greatest of floods yet recorded of the Chagres River that we have just witnessed, which is without doubt second only to that of 1879, and far surpassing in magnitude the five previously recorded since the French Company began operations in the Canal route. Our records show that the month of November had been one of exceptionally heavy rainfalls, and from the 15th to the 18th a freshet of such magnitude swept down the stream that we were induced to consider it as a quasi flood and to class it as the smallest of the great rises of the river. After this occurrence there was a steady downpour over almost the entire Isthmus, as far as the information I have been able to collect demonstrates. From November 21st to December 1st there had fallen at Colon 7.51 inches, at Alhajuela 5.98 inches, at Gamboa 5.71, at Bohio 3.28. By the end of the 2nd of December the distribution on the basin was 11.75 inches at Colon, 8.78 inches at Alhajuela, 8.96 inches at Gamboa, 6.10 inches at Bohio. On the 3rd of December the precipitation increased; the rainfall for that day being 4.75 inches at Colon, 5.16 inches for Alhajuela, 3.71 inches for Gamboa, 3.59 inches for Bohio. These heavy showers of the 2nd and 3rd on ground almost saturated with water produced the great rise, which began to be felt at Alhajuela at 2 p.m. on the 2nd, at Gamboa at 6 p. m., reaching Bohio at 10 o'clock on the night of the 2nd. At Alhajuela the rise was sudden. In 20 hours the maximum elevation was reached, the river attaining here a height above low water of 26.89 feet, and discharging 92,100 cubic feet per second.

"At Gamboa twenty-four hours after its effects were noticed. The river had risen 35.65 feet above low water mark, the discharge at this stage being 76,066 cubic feet per second. Once the maximum was attained the river dropped rapidly and after 36 hours it had subsided 29 feet.

"The crest of the wave did not reach Bohio until 7 a.m. of the 4th, where its elevation was 38.65 feet above low water mark, which is sea level at this place. The discharge at this stage was 108,026 cubic feet per second. At 9 a. m. the elevation had dropped to 36.65 feet, then descended gradually until at 4 p. m. of the 6th it had dropped below the freshet stage.

Panama Railroad between Gatun and Mindi, Flood of 1906

"To obtain comparisons between this and previous floods we can only refer to our estimates for Gamboa and Bohio as these are the only stations at which past floods of the Chagres have been recorded. Considering the maximum discharge per second of time there is no doubt that the present flood surpassed all previous ones in magnitude.[1] If on the other hand we accept 48 hours as the period of danger at Gamboa with the object of comparing these great rises with a view to their regulation before admitting them to the waterway, we must conclude that in magnitude it fell below the floods of 1885 and 1888, due to the shorter duration of its high stage at this station.

"At Bohio the conditions were different, the rise and fall being more gradual, as the lower tributaries contributed well toward the flood, and the reserved volumes stored in the flooded areas of the lower sub-basin maintained its duration during a long period, making the resulting figures of our estimates far above those obtained by General Abbot in his able treatment on this subject.[1] The only flood approaching it in magnitude at Bohio was the flood of 1888, which during a period of 33 hours discharged at the rate of 73,320 cubic feet per second, while for the same period the present flood discharged 84,956 cubic feet.

"In this connection I beg to call your attention to the two different ways by which we will be able in the future to predict these great risings and give advance notice of their coming, to protect the works at Gatun. Both of these methods will be put into execution as soon as the required installations, now well under way, are completed.

"By means of a study of the rain storms, and following General Abbot's analysis in regard to retardation of the rainfall, a graphic chart has been prepared showing the lapse of time between the downfall and its manifestation at Bohio. In this particular case an advance notice of 24 hours could have been given if we could have been able to obtain promptly the rainfall data from Alhajuela, which station has just been re-established.

"The other method is by a study of the relation existing between the gauge heights and discharges at the three stations. By this method we could, after the crest of the flood had passed Alhajuela, advise Gamboa eight hours and Bohio 20 hours in advance as to the height and intensity of the flood and the time it would reach each of the lower stations, thus giving ample time to take the necessary precautions to protect the works at Gatun.

"These studies are receiving careful attention, and when completed a recommendation will be made to you for a system of signals to be used whenever the river is reaching the danger point.

"In measuring this flood both floats and current meters were used. At Gamboa few measurements could be obtained as the rise was so rapid that the banks were soon overflowed and the men were unable to perform any work. There is no good site for gauging high stages of the river in this

[1] Mr. Arango here refers only to floods actually gauged, not including that of 1879 of which only the extreme heights are of record. H. L. A.

vicinity but great care was taken to secure the correct heights, to correct and compare the fluviograph readings; and hourly observations were made during the time of the flood. These observations have permitted us to make the right estimates and save the records here, as the steps of the fluviograph were carried away and we had no means of examining the instrument, which stopped working about ten hours before the maximum height was reached.

"At Bohio the high stage gauging station is well located, and appended you will find a tabulation of the observations taken there.[1] But even here the violence of the flood was such that the great trees that were carried down cut the ropes controlling the gauging car, and completely upset the work. The left bank early in the flood showed signs of giving way, and later a section between thirty and forty feet in from the river slid in, taking with it our cable supports and wrecking the gauging apparatus. The apparatus for releasing floats from the bank was also carried away by trees and we had to resort to taking measurements from our canoe. The work was dangerous and extremely difficult, but the men continued until the canoe was struck by floating logs and put out of commission, being badly cracked. Enough data were secured, together with that obtained during the November flood, to permit us to control our estimates from gauge heights.

"The re-surveying of the cross sections is being pushed as rapidly as possible, and as soon as this work is completed and it is possible to estimate the discharges, especially during the period when the river was falling, a supplementary report will be prepared giving you the completed data, and embodying such other comparisons between this and previous floods as we shall then be enabled to make. In the meantime it has been deemed advisable in this report to give you the general characteristics and magnitude of this flood in comparison with others of which we have record.

"Appended you will find the following—[2]

"In preparing these data the estimated discharges have been given preference over the actual measurements in order that a comparison could be made from the same base used in estimating the past floods, and because I have implicit confidence in the reliability of the rating tables prepared for the three stations by one who is such an authority on the subject matter of this report as General Abbot.

"In conclusion we may say that so far, the system of river regulation, considering this great flood, provides ample limits for the formidable floods that, although of infrequent occurrence, would be a menace to the waterway if improperly cared for."

[1]Omitted, being a memorandum of measurements without reductions. H. L. A.

[2] These consist of charts, photographs, etc., which, except two views, are omitted; and the following list of gauge heights and discharges, which has been used in completing several flood tables elsewhere in the text, especially Tables 25 and 26 and the computations for flood reserves following them. H. L. A.

MR. ARANGO'S APPENDIX C.

BI-HOURLY HEIGHTS ABOVE SEA IN METRES, AND DISCHARGES IN CUBIC METRES.

Hours 1906	Dec. 1		Dec. 2		Dec. 3		Dec. 4		Dec. 5		Dec. 6	
	Height	Disch.	Height	Disch.	Height	Disch.	Height	Disch.	Height	Disch.	Height	Disch.
Alhajuela												
2 a m..............	28.80	78	28.66	62	32.12	999	30.46	479	29 68	225	29.38	167
4 a m..............	28.74	71	28.72	68	33.50	1508	30.31	438	29.63	214	29.37	165
6 a m..............	28.70	66	28.79	77	34.70	1984	30.19	373	29.59	206	29.36	164
8 a m..............	28.67	63	28.80	78	35.46	2292	30.11	320	29.55	199	29.34	160
10 a m..............	28.66	62	28.79	77	36.07	2539	30.05	306	29.53	195	29.33	158
Noon..............	28.67	63	28.78	76	36.15	2572	29.98	289	29.51	191	29.32	157
2 p m..............	28.66	62	28.79	77	35.20	2187	29.93	278	29.49	187	29.32	157
4 p m..............	28.66	62	28.88	104	34.47	1892	29.88	267	29.48	186	29.30	153
6 p m..............	28.64	59	29.17	174	33.63	1559	29.84	258	29.44	178	29.28	150
8 p m..............	28.64	59	29.26	192	32.68	1199	29.80	249	29.42	174	29.27	148
10 p m..............	28.64	59	29.30	200	31.74	870	29.75	239	29.41	173	29.26	146
Midnight..........	28.65	60	30.34	446	30.83	584	29.71	231	29.40	171	29.24	143
Mean..........	28.68	64	29.02	136	33.88	1682	30.00	311	29.51	192	29.31	156
Gamboa												
2 a m..............	15.72	164	15.03	95	17.89	542	23.09	1696	16.16	278	15.62	153
4 a m..............	15.55	146	15.03	95	18.92	738	22.26	1491	16.09	207	15.58	149
6 a m..............	15.42	132	15.06	97	20.05	975	21.44	1293	16.00	196	15.56	147
8 a m..............	15.32	122	15.07	98	21.20	1237	20.68	1116	15.96	191	15.54	145
10 a m..............	15.22	112	15.14	105	22.56	1565	19.88	938	15.91	186	15.51	142
Noon..............	15.17	108	15.15	106	23.44	1784	19.00	754	15.86	180	15.50	141
2 p m..............	15.14	105	15.17	108	24.20	1977	18.15	589	15.83	177	15.48	139
4 p m..............	15.11	102	15.18	109	24.65	2092	17.46	466	15.79	172	15.46	136
6 p m..............	15.07	98	15.29	136	24.89	2154	16.88	371	15.75	168	15.44	134
8 p m..............	15.05	96	15.50	179	24.73	2113	16.54	319	15.70	162	15.42	132
10 p m..............	15.04	96	16.05	249	24.42	2034	16.37	294	15.66	158	15.39	129
Midnight..........	15.04	96	16.90	374	23-80	1876	16.30	284	15.64	156	15.38	128
Mean..........	15.24	115	15.38	146	22.56	1591	19.00	801	15.86	186	15.49	140
Bohio												
2 a m..............	4.45	463	2.77	190	4.54	478	10.74	2482	9.56	1923	4.92	545
4 a m..............	4.39	453	2.72	185	5.71	703	11.10	2672	9.22	1780	4.67	500
6 a m..............	4.21	424	2.68	181	6.40	864	11.56	2930	8.90	1653	4.49	470
8 a m..............	4.01	394	2.66	179	7.02	1028	11.35	2810	8.49	1499	4.30	438
10 a m..............	3.77	358	2.64	177	7.43	1147	11.17	2710	8.01	1331	4.16	416
Noon..............	3.58	332	2.65	178	7.85	1279	11.10	2672	7.60	1199	4.05	400
2 p m..............	3.38	280	2,70	183	8.10	1362	10.99	2613	7.19	1076	3.90	377
4 p m..............	3.22	236	2.71	184	8.50	1502	10.87	2549	6.69	938	3.87	344
6 p m..............	3.11	225	2.71	184	8.88	1645	10.70	2461	6.29	837	3.65	287
8 p m..............	3.00	213	2.72	185	9.29	1809	10.46	2340	5.90	745	3.60	281
10 p m..............	2.91	204	2.78	211	9.74	2002	10.18	2204	5.55	669	3.53	272
Midnight..........	2.84	197	3.40	308	10.28	2252	9.87	2061	5.23	604	3.46	364
Mean..........	3.57	315	2.76	195	7.81	1339	10.84	2542	7.39	1188	4.05	391

The highest gauge reading at Alhajuela was 36.24, indicating a discharge of 2,608 cubic metres per second (92,100 cubic feet); the largest average discharge in 48 hours was 1.005 cubic metres per second (35,490 cubic feet). At Gamboa these figures were 24.89, 2,154 (76,066), and 1,200

(42,377). At Bohio they were 11.78, 3,059 (108,026), and 2,106 (74,371). During the entire six days the discharge at Alhajuela (14,973 cubic feet per second) was 85% of that at Gamboa (17,516 cubic feet), and 43% of that at Bohio (34,537 cubic feet). That at Gamboa was 51% of that at Bohio.

The Freshet Problem

But the great floods are by no 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 ex-

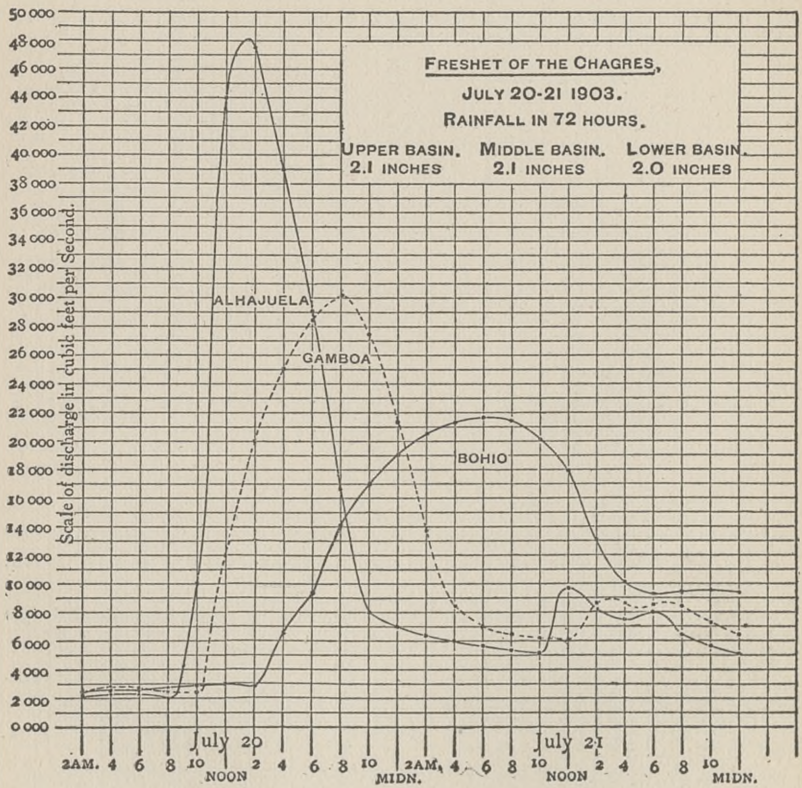


Fig. VIII. Typical Freshet of the Chagres

pected. 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

TABLE 24.—FRESHET OF JULY 20-21, 1903

Hours	Height above sea in metres		Discharge in cubic feet per second	
	July 20	July 21	July 20	July 21
	ALHAJUELA			
2 a. m.	28.64	29.20	2119	6357
4 a. m.	28.66	29.14	2225	5933
6 a. m.	28.66	29.10	2225	5651
8 a. m.	28.63	29.07	2084	5439
10 a. m.	29.70	29.03	10136	5191
noon	32.80	29.66	43934	9810
2 p. m.	33.15	29.45	48560	8193
4 p. m.	32.40	29.37	38778	7593
6 p. m.	31.60	29.42	29066	7946
8 p. m.	30.40	29.17	16352	6145
10 p. m.	29.45	29.10	8193	5651
mid't	29.28	29.01	6922	5050
	GAMBOA			
2 a. m.	14.80	17.00	2613	13844
4 a. m.	14.90	16.00	2931	8617
6 a. m.	14.88	15.64	2861	6957
8 a. m.	14.80	15.54	2613	6534
10 a. m.	14.78	15.48	2543	6286
noon	17.10	15.42	12009	6004
2 p. m.	18.00	16.00	19919	8617
4 p. m.	18.76	16.00	25004	8617
6 p. m.	19.28	15.90	28712	8158
8 p. m.	19.48	15.90	30160	8158
10 p. m.	19.08	15.70	27264	7240
mid't	18.20	15.56	21225	6604
	BOHIO			
2 a. m.	1.31	5.10	2543	20448
4 a. m.	1.32	5.20	2578	21119
6 a. m.	1.35	5.28	2649	21684
8 a. m.	1.42	5.27	2790	21614
10 a. m.	1.47	5.05	2931	20130
noon	1.47	4.70	2931	17835
2 p. m.	1.42	3.80	2790	12820
4 p. m.	2.40	3.20	6746	9959
6 p. m.	3.40	3.00	9078	9112
8 p. m.	4.06	3.06	14162	9359
10 p. m.	4.55	3.10	16952	9536
mid't	4.89	3.08	19071	9465

extreme, shown in Table 24. Figure 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 25 has been prepared to give this information. High rises of the Chagres rarely continue more than about 24 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 25 gives both the average and the maximum volume at each locality, as well as the rainfall in each sub-basin 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 the maximum volumes furnish the 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.

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 only meagre flood data have 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 prob-

TABLE 25.—TYPICAL FRESHETS AND FLOODS, CLASSED BY LOCUS OF RAINFALL

Date	Rainfall in sub-basin in 72 hours			Discharge in cubic feet per second, for 24 hours					
				Alhajuela		Gamboa		Bohio	
	upper, inches	middle, inches	lower, inches	average	maximum	average	maximum	average	maximum
	Rainfall chiefly in upper basin.								
May, 1899	6.0	0.3	1.8	10,348	30,725	9,641	20,484	10,807	17,588
Aug., 1900	3.9	1.7	1.3	10,383	22,850	10,736	20,625	14,374	18,612
Aug., 1903	4.7	3.2	1.5	11,760	30,831	17,270	25,922	21,402	27,547
Nov., 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.								
Dec., 1900	1.1	0.8	2.6	14,762	23,486	14,974	21,932	18,259	22,885
Jan., 1902	1.2	4.1	7.7	10.389	23,945	22,532	26,629	37,153	38,107
Dec., 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
	Rainfall well distributed.								
Aug., 1899	1.5	1.3	1.1	15,030	29,771	16,634	26,205	19,919	25,887
Nov., 1899	2.5	3.9	3.1	11,160	30,937	12,855	23,132	18,859	24,333
Oct., 1900	3.0	3.6	1.9	11,549	26.805	14,621	23,521	16,528	20,837
Nov., 1901	6.0	4.5	6.1	11,[illegible]01	19,071	16,917	25,075	28,995	33,233
same	2.6	1.8	2.1	13,738	22,497	15,116	21,296	24,474	26,699
same	4.8	2.9	4.6	21,119	43,581	25,357	36,871	33,727	40,508
Aug., 1902	1.3	1.6	2.3	11,725	30,231	14,415	23,803	14,586	19,777
Oct., 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
Dec., 1903	3.5	3.0	3.2	14,550	19,989	11,725	14,339	17,870	19,623
same	2.8	3.0	3.0	9,747	16,917	12,679	19,354	19,777	21,826
Jan., 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
	Four great freshets and the six floods.								
Dec., 1888	—	—	—	—	—	30,867	40,014	—	—
May, 1897	—	—	—	—	—	30,549	42,380	—	—
Nov., 1879	—	—	—	—	—	—	78,615	—	112,731
Nov., 1885	—	—	—	—	—	57,001	64,488	—	74,801
Dec., 1885	—	—	—	—	—	40,755	44,923	—	47,501
Dec., 1888	—	—	—	—	—	51,809	58,202	—	79,004
Dec., 1890	—	—	—	—	—	50,185	65,371	64,347	71,657
Dec., 1893	—	—	—	—	—	39,449	43,157	48,490	51,068
Nov., 1906	—	—	—	25,463	43,121	30,793	40,075	43,158	46,292
Dec., 1906	—	—	—	59,403	92,100	62,722	76,066	90,340	108,026

ably 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. Fig. VI illustrates these conditions.

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.

Inflow to the Canal Route at Gamboa.—The entrance to the projected lake below Gamboa is for a few miles rendered narrow by bounding hills, and it is believed that a study of the data contained in Table 25, which may be largely increased from the records of the French Company if desired, will convince hydraulic engineers that such volumes, carrying as they do more or less sand and gravel, should be excluded from a great trade route to be used by ocean steamers. By a lake at Alhajuela to regulate the flow, the river may readily be transformed into a stream as gentle as it now is in the dry season; but strange as it may seem this lake was not regarded as essential by the Isthmian Canal Commission of 1899-01. There was no difference in opinion on the part of the *Comité Technique,* whatever might be the height of the summit level of the canal, that such volumes could not be neglected. In a word, the Chagres should be regulated at its entrance into the transit route as well as in its lower course. As has been shown above, the volume at Gamboa in the standard flood fell but little below 80,000 cubic feet per second, and even in the frequent freshets the volume would be too large not to cause annoyance to great ocean steamers in transit.

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 26, will be found convenient for reference. It will be remembered that low water at Bohio is taken as 0 metres, and at Gamboa as 14.0 metres above mean sea level.

TABLE 26.—SUMMARY OF GREAT FLOODS

Flood	At Gamboa				At Bohio			
	Max. height, ft. above l. w.	Discharge in ft. sec.			Max. height, ft. above l. w.	Discharge in ft. sec.		
		Maximum	In 48 hours	Per cent.		Maximum	In 48 hours	Per cent.
1906, Nov.	22.10	40,075	25,003	62	26.08	46,292	38,738	83
1906, Dec.	35.65	76,006	42,377	56	38.65	108,026	74,371	69
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	?	?
1885, Nov.	31.50	64,488	43,404	67	33.79	74,800	?	?
1885, Dec.	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 48 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 48 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 rule higher, as is natural. Furthermore, the canal at sea level having been largely completed by the old Company as far as Bohio, and this location being suitable for a dam, it was naturally selected as the site to be preferred; 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 three 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 three known floods, it will be found from the tables of hourly flow that in 1906 the discharge equalled or exceeded 42,000 cubic feet per second between 10 p.m. of November 16 and 4 p.m. of November 17, a period of 18 hours, and between noon of December 3 and 2 p.m. of December 5, a period of 50 hours; in 1893 between the hours of 10 a.m. on December 21 and 1 p.m. on December 22, a period of 27 hours; and in 1890 between the hours of 7 p.m. on December 1 and 3 a.m. on December 3, a period of 32 hours,—the intermediate average discharges being 44,358, 73,105, 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 26. It remains to make use of these data for estimating the volumes which passed below Bohio in the four unknown floods by comparing them with the three known floods as standards.

STANDARD, THE FLOOD OF 1906 (73,105 FT. SEC. FOR 50 HOURS)

Flood of 1879

$$\frac{73{,}105}{108{,}026} \times 112{,}730 = 76{,}288 \text{ ft. sec. for } \frac{39.4}{38.7} \times 50 = 50.9 \text{ hours}$$

STANDARD, THE FLOOD OF 1893 (47,400 FT. SEC. FOR 27 HOURS).

Flood of 1888

$$\frac{47{,}400}{51{,}100} \times 79{,}000 = 73{,}320 \text{ ft. sec. for } \frac{34.7}{28.5} \times 27 = 32.9 \text{ hours}$$

Flood November, 1885

$$\frac{47{,}400}{51{,}100} \times 74{,}800 = 69{,}420 \text{ ft. sec. for } \frac{33.8}{28.5} \times 27 = 32.0 \text{ hours}$$

Freshet December, 1885

$$\frac{47{,}400}{51{,}100} \times 47{,}466 = 44{,}100 \text{ ft. sec. for } \frac{26.4}{28.5} \times 27 = 25.0 \text{ hours}$$

Flood of 1879

$$\frac{47{,}400}{51{,}100} \times 112{,}730 = 104{,}600 \text{ ft. sec for } \frac{39.4}{28.5} \times 27 = 37.3 \text{ hours}$$

STANDARD, THE FLOOD OF 1890 (60,300 FT. SEC. FOR 32 HOURS)

Flood of 1888

$$\frac{60{,}300}{71{,}660} \times 79{,}000 = 66{,}460 \text{ ft. sec. for } \frac{34.7}{32.1} \times 32 = 34.6 \text{ hours}$$

Flood November, 1885

$$\frac{60{,}300}{71{,}660} \times 74{,}800 = 62{,}900 \text{ ft. sec. for } \frac{33.8}{32.1} \times 32 = 33.7 \text{ hours}$$

Freshet December, 1885

$$\frac{60{,}300}{71{,}660} \times 47{,}466 = 39{,}940 \text{ ft. sec. for } \frac{26.4}{32.1} \times 32 = 26.3 \text{ hours}$$

Flood of 1879

$$\frac{60{,}300}{71{,}660} \times 112{,}730 = 94{,}800 \text{ ft. sec. for } \frac{39.4}{32.1} \times 32 = 39.3 \text{ hours}$$

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:

Freshet Nov., 1906 (actually measured)	3,508 acre-feet
Flood Dec., 1906 (actually measured)	128,533 acre-feet
Flood of 1893 (actually measured)	12,100 acre-feet
Flood of 1890 (actually measured)	48,400 acre-feet
Flood of 1888 (compared with 1893)	85,100 acre-feet
Flood of 1888 (compared with 1890)	69,900 acre-feet
Flood Nov., 1885 (compared with 1893)	72,600 acre-feet
Flood Nov., 1885 (compared with 1890)	58,200 acre-feet
Freshet, Dec., 1885 (compared with 1893)	4,330 acre-feet
Freshet Dec., 1885 (compared with 1890)	Nothing
Flood of 1879 (compared with 1906)	144,326 acre-feet
Flood of 1879 (compared with 1893)	193,200 acre-feet
Flood of 1879 (compared with 1890)	171,400 acre-feet

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. The freshet 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 project. Furthermore, bearing in mind that the use of the ratio eight-tenths in reducing the gaugings (adopted to avoid any possible over-estimate of low-water supply) entails a safety coefficient for flood volumes, it was agreed unanimously to adopt 250,000,000 cubic metres (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.

Dual Lake Solution.—It will appear further on that any single lake above Bohio to hold back so large a reserve must be given a height incompatible with other fundamental conditions.

Nature has favored the plan with two lakes. An excellent dam site exists at Alhajuela, about 9 or 10 miles above in direct line, where the surveys have demonstrated that ample reserves may be stored for all the needs of the canal in the dry season, and for a flood reserve of 150,000,000 cubic metres (121,600 acre feet) to be held back and delivered gradually, as desired, after the flood has ceased. With such an upper lake there will be, of course, no difficulty in regulating the volume to be admitted to Lake Bohio in ordinary freshets, even to the extent of giving a practically uniform flow to the stream.

It remains to consider how the 250,000,000 cubic metres constituting the total flood reserve should be divided between the two lakes. Occurring so rarely as do the great floods, it would appear that a volume of 1,000 cubic metres per second (35,000 cubic feet), may be permitted so exceptionally to enter Lake Bohio, giving in the contracted portion near Gamboa a velocity of about 1.6 miles per hour. Adopting this figure, the reserve to be held back at Alhajuela may be computed upon the same principles that have been applied above at Bohio. The conclusions will be even more definite, since all the floods except that of 1879 were actually measured at Gamboa. The following is the computation to make known the reservoir capacity that would have been required at Alhajuela to restrict the maximum volume allowed to enter Lake Bohio in each of the great floods to the quantity of 35,000 cubic feet per second.

STANDARD, THE FLOOD OF 1906 (60,921 FT. SEC. FOR 26 HOURS)

Flood of 1879

$$\frac{60{,}921}{76{,}006} \times 78{,}614 = 63{,}011 \text{ ft. sec. for } \frac{36.6}{35.6} \times 26 = 26.7 \text{ hours}$$

STANDARD, THE FLOOD OF 1893 (39,378 FT. SEC. FOR 16 HOURS)

Flood of 1879

$$\frac{39{,}378}{43{,}086} \times 78{,}614 = 71{,}850 \text{ ft. sec. for } \frac{36.65}{25.33} \times 16 = 23.16 \text{ hours}$$

STANDARD, THE FLOOD OF 1890 (50,291 FT. SEC. FOR 23 HOURS)

Flood of 1879

$$\frac{50{,}291}{65{,}371} \times 78{,}614 = 60{,}480 \text{ ft. sec. for } \frac{36.65}{31.82} \times 23 = 26.50 \text{ hours}$$

STANDARD, THE FLOOD OF 1888 (48,947 FT. SEC. FOR 45 HOURS)

Flood of 1879

$$\frac{48{,}947}{58{,}132} \times 78{,}614 = 66{,}190 \text{ ft. sec. for } \frac{36.65}{31.37} \times 45 = 52.57 \text{ hours}$$

STANDARD, THE FLOOD OF NOV., 1885 (51,456 FT. SEC. FOR 31 HOURS)

Flood of 1879

$$\frac{51{,}456}{64{,}488} \times 78{,}614 = 62{,}730 \text{ ft. sec. for } \frac{36.65}{31.50} \times 31 = 36.03 \text{ hours}$$

STANDARD, THE FLOOD OF DEC., 1885 (40,826 FT. SEC. FOR 24 HOURS)

Flood of 1879

$$\frac{40{,}826}{44{,}923} \times 78{,}614 = 71{,}460 \text{ ft. sec. for } \frac{36.65}{24.11} \times 24 = 36.48 \text{ hours}$$

Reducing, as before, to a common unit for comparison.

Freshet of Nov., 1906 (actually measured)	2,393 acre-feet
Flood of Dec., 1906 (actually measured)	55,698 acre-feet
Flood of 1893 (actually measured)	5,790 acre-feet
Flood of 1890 (actually measured)	29,050 acre-feet
Flood of 1888 (actually measured)	51,880 acre-feet
Flood of Nov., 1885 (actually measured)	42,140 acre-feet
Freshet of Dec., 1885 (actually measured)	11,560 acre-feet
Flood of 1879 (compared with 1906)	61,809 acre-feet
ditto (compared with 1893)	70,500 acre-feet
ditto (compared with 1890)	55,800 acre-feet
ditto (compared with 1888)	135,500 acre-feet
ditto (compared with Nov., 1885)	82,700 acre-feet
ditto (compared with Dec., 1885)	109,600 acre-feet

These figures would seem to leave no doubt, if for no other reason than to guard against annoying currents, gravel and sand deposits, and delays in canal operation at the contracted entrance to Lake Bohio, that the lake at Alhajuela should be regarded as an essential element of the regulation of the Chagres. It should provide for the temporary storage of about 150,000,000 cubic metres (121,600 acre feet), leaving the remaining 100,000,000 cubic metres (81,110 acre feet), to be held back in Lake Bohio. This was the plan proposed by the engineers of the New Company in the low-level variant of their project.

These flood reserves have been questioned, in *Le Génie Civil,* as perhaps needlessly large, because based on the estimated requirements of the flood of 1879 concerning which existing data are defective; and the idea has been advanced that the flood of 1888 might better have been adopted as the standard. The chief point of uncertainty at Bohio is the probable duration of excessive discharge, which neither in the flood of 1879 nor in that of 1888 is of record. It will be noted from the above figures that at Gamboa, where several floods are well understood, the conclusions as to their relative importance reached by the study at Bohio are amply confirmed. In an element of so great importance as flood regulation in a route to be traversed by the commerce of the world, any error should lie on the side of safety. Furthermore, the unexampled duration of high water at Gamboa in the month of December, 1888, (424 hours above the lower limit of freshets), suggests that if more complete data even for that month were available the requirements estimated above based on what occurred in the 45 hours of greatest flow might be increased. What is certain is that in the floods of 1879, 1888 and 1906 the river exhibited powers of offense not judiciously to be underrated.

In fine, by the project adopted by the New Panama Canal Company the entire river is regulated. Neither in the great floods nor in the frequent freshets will the passage of the largest ships be retarded at the entrance of the lake near Gamboa; locks of moderate lift will afford ready access to it at Bohio; and, as will next be shown, the volume allowed to escape to the region below will not exceed what can readily pass through separate channels to the sea without in any degree encroaching upon the canal. Incidentally, the difficulties in the construction of a dam at Bohio will be very greatly reduced, as compared with any single-lake project, and, as will appear below, the low-water reserve will be secured against any possible danger of reduction by undue infiltration. Such are the merits of this dual-lake plan of regulation.

Volume below Bohio.—The Isthmian Canal Commission of 1899-01, charged with a study of all possible routes and laboring under great pressure for an early report, apparently underestimated the danger of flooding the district below the lake. As this has usually been submerged in the great floods, involving interruption to transit by the railroad, and dangers to the projected canal at such times, the matter was carefully investigated by the *Comité Technique*, and the conclusion was reached that the overflow should be restricted to 1,200 cubic metres per second (42,380 cubic feet).

The plan of the Isthmian Canal Commission of 1899-01 provides for automatic regulation, allowing the flow to pass over a fixed spillway 2,000 feet in length. It estimates that with 5 feet on the crest about 78,000 cubic feet per second will escape, and with 7.5 feet about 140,000, and that the latter will more than meet all demands.

The *Comité Technique* preferred the system of regulated outflow that has proved to be an entire success on the Manchester Ship Canal. The weir crest would be fixed at about a metre (3.3 feet) below the normal level of the lake. Counterpoised gates operated independently would permit the outflow to be easily and rapidly regulated. To secure a uniform outflow never exceeding 1,200 cubic metres (42,380 cubic feet) a length of crest of about 144 metres (472 feet) would be required, based on a largest flood discharge of the river at Bohio of 2,640 cubic metres (93,236 feet) per second for 48 hours, the two lakes co-operating. While an automatic system of controlling the overflow is undeniably the more simple it contemplates a constantly increasing discharge during a flood, and leaves the maximum volume to be determined by the maximum height of flow over the crest. With a system of movable gates this discharge admits of regulation to a uniform and safe volume during the entire period, an important matter when the capacity of the channel below is limited, as is the case below the Bohio dam. The duty of the operator here involves no real difficulty, since he has only to watch the level of the water in the lake and below and be guided accordingly. Under ordinary conditions the automatic system would probably meet all needs, but in floods the results would be more doubtful. Furthermore the two systems admit of combination.

Percolation from Lakes.—Before considering the matter of water supply for the canal during the season of low water, it seems desirable to refer to a criticism which has been raised against dependence upon artificial lakes in which to store such reserves.

In the Additional Report of the Senate Committee on Interoceanic Canals dated January 7, 1901, appears the following statement:

"We cannot know in advance what an artificial lake can supply to meet the emergencies of the dry season in a torrid country where the bottom of the basin is left in its natural condition and may be inadequate to retain the waters impounded in it, and this problem cannot be determined except by long experience. In this case no effort has been made to solve this vital question; it is left entirely to conjecture. As this is a factor in the problem on which the entire question of a water supply depends, the absence of any practical effort to solve it is conclusive against its adoption."

The writer of this paragraph was ill informed. The problem had been carefully considered by the engineers of the New Company, and a preliminary study of the results of the investigation had appeared in a Government publication (the Monthly Weather Review) which was issued in the United States in June, 1900.

It is clear, in the case of any artificial reservoir, that without actually flooding the region in question dependence must be placed on one or both of two lines of research—the nature of the geological formation, and a comparison between the volume of water received from the clouds and that flowing to the sea by the watercourses. In the case of the Chagres valley, the geological examinations gave every promise that the water impounded would be retained with even less infiltration than usual; but, following their habit of neglecting nothing which could throw light upon the problem, the engineers of the New Company instituted what is perhaps the most elaborate study of the ratio between downfall and drainage that has yet been made in a tropical valley like that of the Chagres above Bohio. The results leave no doubt that the subsoil is fully saturated with water, and that no open route exists for any considerable subterranean escape. On the contrary, the stream receives large contributions from this source.

In round numbers it appears that of the entire rainfall in the basin about one-third evaporates, another third flows off directly by the bed of the river, and the residue, after a retardation of perhaps three months by its passage through the soil, ultimately reaches the river as ground water. During the dry months it supplies much the larger part of the flow. In fine, the conditions of this tropical basin, as compared with those existing in the northeastern portion of the United States, indicate per square mile about 2.5 times the rainfall, 3.3 times the outflow, and 1.5 times the evaporation.

A study of these data, collected with no little labor for technical use in connection with the canal problem, demonstrated that they also throw light upon matters of general scientific interest. For this reason the next Chapter will be devoted to a somewhat full discussion of them, rather than to abridge them here within limits suited to the matter directly under consideration. It should be stated that the paper first appeared in the form of a monograph in the Monthly Weather Review for February, 1904.

WATFR SUPPLY OF THE CANAL, FRENCH PROJECT.

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 given on page 134 demonstrates that the river has recently been passing through one of its minimum epochs.

The following conclusions are based on Table 23. 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 742 cubic feet,—the latter occurring in 1901 and 1903. 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 in passing the locks, 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 1,512 cubic feet, 1,915 cubic feet, and 2,800 cubic feet,—the latter noted in 1905. 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 320 days annually of ten 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 twenty-four 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 project formulated by the *Comité Technique* rather than to introduce uncertain modifications. This project was based on the probable commercial requirements of the canal for the next fifty years, after extensive correspondence with leading shippers and ship-builders.

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.

$$\text{(7)} \quad \text{Total lockages on slope} = \frac{N + 2}{4} V$$

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 millimetres (0.24 inches) per 24 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 manœuvres 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 metres (151 feet) at the dam at Alhajuela and at the locks at Bohio. In this manner about 4,300 horse power 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 27 exhibits the continuous water flow per second required.

Table 27.—Requisite Volume per Second

Requirements	Traffic of 10,000,000 tons		Traffic of 23,000,000 tons	
	Cubic metres	Cubic feet	Cubic metres	Cubic feet
For lockages	10	353	24	848
For leakages at gates	3	106	3	106
Evaporation and infiltration	5	177	5	177
False manœuvres	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 ten million tons, it is 118,000,000 cubic metres; and for twenty-three million tons, 232,000,000 cubic metres.

The site at Alhajuela is exceptionally favorable, as will appear from the summary of the project for the dam adopted by the New Company, given in Chapter VI. The dimensions of the lake furnish a capacity for low water reserves at 170,000,000 cubic metres, with a further allowance of 150,000,000 cubic metres 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 metres per metre 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.

Now that we have inherited the work, it behooves American engineers to recognize that these facts have been established by most thorough and painstaking investigations, conducted for many years under difficulties that would have discouraged engineers less able and devoted than Monsieur Maurice Hutin, the Director-General, and Monsieur Louis Choron, the director of investigations and of construction, and their able assistants on the Isthmus. Such data are of vital importance, and could only have been secured by long years of investigations intelligently conducted.

Tropical and Temperate Stream Flow

The Chagres traverses a basin clothed with the luxuriant vegetation of the tropics and subjected to rainfall and climatic conditions so unlike those of the United States that it is not without interest to contrast elements resulting in similar volumes. The Roanoke River affords a good standard of comparison. Above Neal, North Carolina, its drainage basin covers an area of about 8,717 square miles, with an annual rainfall of about 51 inches. The corresponding figures for the Chagres are about 700 square miles and 112 inches. The Roanoke basin is largely covered by forests in the mountainous district, with swamps in the lower region; and in this respect the Chagres is not unlike, but the tropical growth is more dense. Both rivers are subject to sudden oscillations in water level, but those of the Roanoke often cover several days while those of the Chagres rarely exceed twenty-four hours. The highest recorded flood at Neal attained, in March, 1897, a height of 30 feet above the extreme low water of September, the respective volumes being 83,-000 cubic feet per second in the former and 2,000 cubic feet in the latter. The corresponding figures at Bohio, in November, 1879, were 113,000 cubic feet, to compare with an extreme low water volume of 400 cubic feet, the flood occurring as usual near the end of the year. The volume of the Roanoke at low stages up to about 13 feet above low water is larger than that of the Chagres, but above that level it is remarkably similar. Thus simultaneous gaugings of five consecutive months in 1896, made at Neal by the U. S. Geological Survey and at Bohio by the New Company, indicated average volumes for that period of 5,761 and 5,849 cubic feet per second respectively.

The old popular belief that the regulation of the floods of the Chagres presents unprecedented difficulties, although often asserted, is erroneous. Thus the works of improvement now in progress upon the Warrior and its tributary the Black Warrior of Alabama, offer conditions far less favorable. At Tuscaloosa an extreme oscillation of 67 feet is of record, with a rise of 20 feet in 4 hours. The discharges range from 150 to 150,000 cubic feet per second. Such extremes have never been approached by the Chagres. All that is required for that river is a judicious plan of regulation based on well established principles.

CHAPTER VI.

ULTIMATE DISPOSAL OF RAINFALL IN THE BASIN ABOVE BOHIO

The question of what becomes of the precipitation falling from the clouds upon a given catchment basin—what part escapes through the channels of the streams, what part is evaporated, what is absorbed by plant life, and finally what part sinks into the earth as ground water—has received much attention from hydraulic engineers by reason of its important bearings upon the water supply of cities, the irrigation of arid regions, and the development of water power. To be of utility, such studies must be based upon long-continued measurements of the rainfall at localities suitable to afford a true estimate of the average precipitation upon the region in question during each of the different seasons of the year, together with accurate gaugings of the outflowing streams during the same periods. For a complete solution, further observations to determine the evaporation from land and water surfaces and the absorption of moisture by plants are desirable to furnish a check upon the values found for the other and more important elements, but the extreme difficulty of such studies has usually proved a bar to undertaking them. It must not be forgotten, however, that a portion of the water apparently lost by infiltration into the earth may ultimately find its way into the streams as ground water, and as such may be detected, at least approximately, by a careful investigation of the ratio between downfall and drainage in different seasons of the year. Even in this simplified form the labor and expense involved in the needful measurements have restricted their application to a few localities, and those generally situated in populous and temperate districts.

In connection with their other technical investigations the engineers of the New Panama Canal Company found it obligatory to study some of these questions with considerable attention, and this abstract of the researches is written in the hope that the facts and figures may prove useful in throwing light upon the more general problem of the ultimate disposal of rainfall.

The Isthmus of Panama is a locality specially favorable to studies of this character. Ice and snow, which have usually complicated such investigations, are here unknown. The region is practically in its natural condition, densely covered with the luxuriant growth of the Tropics. The temperature of the air, which largely influences evaporation, hardly varies from month to month and from year to year, thus in a great measure eliminating one important element of relative uncertainty. Finally, the rainfall is excessive, and is sharply divided between a dry season of three months and a rainy season of seven months, with two intermediate months of less marked character. This fact, as will appear later, has greatly favored the analysis. It seems not improbable that results obtained under so favorable conditions may not only be applicable to similar regions in the Tropics but may also throw light upon certain elements common to more northern latitudes.

The district covered by these measurements is the basin of the Chagres above Bohio, at which locality was projected the lower reservoir dam creating a large lake to be traversed by shipping as part of the canal route. Under present conditions all outflow from above passes Bohio. The catchment basin is naturally divided into three subbasins, the lower extending to Gamboa, where the Chagres first joins the canal route; the middle extends thence to Alhajuela, where a second dam should be placed; the upper includes the valley above this point. The surveys of the Panama Railroad, supplemented by those of the two Panama Canal companies, have well defined the watershed of the two lower subbasins, as well as the western and much of the southern boundaries of the upper subbasin;

but a gap exists on the northern and eastern boundary of the latter where the line of demarcation is somewhat uncertain for a distance of about 35 miles. One point nearly in the middle of the unknown portion was determined by a reconnaissance made by a party of the Isthmian Canal Commission of 1899-1901 coming from the San Blas district to the head of the eastern branch of the upper Chagres, and this point together with the well known general character of the district, low ridges separated by narrow gorges, have enabled the ill-defined part of the boundary to be laid down on the map with fair precision. All the rest of the entire watershed of the basin being accurately determined, no error can exist in the estimated area large enough to sensibly affect any practical conclusions to be based on the study. The following table exhibits, in statute miles, the dimensions of the basin, which is a hilly rather than a mountainous district, and much of it is covered with a dense tropical growth. The highest summits rarely if ever rise more than about 1,500 feet above sea level:

Subbasin	Basin above Bohio				Length of bed	Number of affluents
	Area	Per cent.	Length	Width		
Upper	320	46	18	18	31	?
Middle	130	18	7	18	11	15
Lower	250	36	11	23	20	17
Total	700	100	....	....	70	....

Before stating the general conclusions resulting from the study it will be well to consider in some detail the several important elements upon which they are based.

Rainfall in the Basin Above Bohio

So many data have been collected respecting rainfall upon the Isthmus of Panama that the monthly and yearly precipitation is well understood. The records kept by the Panama Railroad Company at Colon are nearly continuous since 1862, and many have been kept by the two Canal Companies on the Pacific Coast, and in the interior,

TABLE 28.—AVERAGE RAINFALL, IN MILLIMETERS, IN THE BASIN OF THE CHAGRES

Month	Basin above Bohio							Basin above Gamboa						
	1898	1899	1900	1901	1902	1903	Means	1898	1899	1900	1901	1902	1903	Means
January	140	156	89	19	464	16	147	99	152	81	15	232	14	99
February	11	96	24	15	12	5	27	6	104	4	9	10	5	23
March	27	56	12	37	52	17	34	20	33	11	38	42	15	27
April	108	27	74	43	163	32	75	78	24	71	48	148	22	65
May	238	267	234	320	266	271	266	230	285	264	298	270	273	270
June	283	236	383	270	183	263	270	267	193	377	280	201	273	263
July	579	403	432	279	268	400	394	512	431	451	225	336	450	401
August	532	305	311	428	241	350	361	395	303	320	391	204	376	332
September	198	304	330	370	270	273	291	182	302	337	340	267	149	263
October	301	334	372	455	341	356	361	255	584	360	454	317	340	385
November	363	285	416	655	388	487	432	341	299	390	637	405	504	429
December	133	118	57	173	119	455	176	131	114	54	135	132	456	170
Year	2,913	2,587	2,734	3,064	2,767	2,925	2,834	2,516	2,824	2,720	2,870	2,564	2,877	2,729

Month	Basin above Alhajuela							Basin Alhajuela-Gamboa						
January	....	151	100	19	254	15	108	....	151	36	7	180	11	77
February	....	104	5	13	12	6	28	....	104	3	4	7	3	24
March	....	33	15	44	35	18	29	....	33	2	25	60	9	26
April	....	24	62	51	128	27	58	....	24	93	42	192	12	73
May	....	285	285	280	284	287	284	....	285	215	340	270	240	270
June	....	193	374	293	204	273	267	....	193	381	250	195	275	259
July	....	500	464	227	376	462	406	....	269	421	218	242	421	314
August	....	317	351	386	193	381	326	....	269	247	403	227	363	302
September	....	313	337	353	275	254	306	....	273	337	309	248	224	278
October	....	342	376	443	322	325	362	....	252	322	463	307	374	344
November	....	321	427	689	399	567	480	....	247	305	515	420	358	369
December	....	138	67	131	152	463	190	....	58	25	147	86	439	151
Year	....	2,721	2,863	2,929	2,634	3,078	2,844	....	2,158	2,387	2,723	2,414	2,731	2,487

Month	Basin Gamboa-Bohio						
January	192	182	102	25	453	52	168
February	17	79	8	24	14	5	25
March	39	59	15	33	67	19	39
April	152	32	77	33	186	48	85
May	253	240	180	353	258	265	258
June	310	299	389	251	151	244	274
July	687	346	396	367	152	312	377
August	743	304	291	484	212	304	390
September	221	284	314	412	271	316	303
October	469	346	388	447	276	352	380
November	462	243	453	677	349	417	434
December	112	113	61	233	95	415	171
Year	3,657	2,527	2,674	3,339	2,464	2,749	2,904

since 1881. Those specially valuable in the present study date from 1895, when the daily measurements of discharge were extended to include Alhajuela, near the site of the projected upper dam. All rain gauges were read and recorded daily. The respective heights above the ground in their vicinity are the following: At Colon, 30 feet; at Alhajuela, 8 feet; at Gamboa, 36 feet; at Bohio, 6 feet; and at La Boca, 2.5 feet.

What is needful in the present study is a knowledge of the average monthly rainfall in each of the three subbasins, from which that in the entire basin may be deduced. Bohio and Gamboa are near each other and at the extremities of the lower subbasin; Gamboa and Alhajuela are also near each other and at the extremities of the middle subbasin; finally, from the fact that the Pequeni, the largest and most important branch of the upper Chagres, heads near Porto Bello only about five miles from the Atlantic coast, where the conditions as to rainfall are similar to those at Colon, it may be assumed that a mean between the recorded rainfall at Alhajuela and at Colon will fairly represent the precipitation in the upper subbasin. Introducing the areas of the subbasins, and reducing, the following expressions result for the rainfall, in millimeters, in the entire basin and for that above Gamboa as well; in them B, G, A, and C denote rainfall, in millimeters, at Bohio, Gamboa, Alhajuela, and Colon, respectively:

(8) Rainfall above Bohio $= 0.323\ (0.6\ B + 0.9\ G + A + 0.7\ C)$.

(9) Rainfall above Gamboa $= 0.5\ (0.3\ G + A + 0.7\ C)$.

Table 28 presents the rainfall, in millimeters, computed as above indicated for the several basins under consideration during the entire period of these studies. As rain records at Alhajuela were lacking in 1898 and in the first six months of 1899, the figures for those months have been found by assuming that the rainfall in the upper subbasin is represented by that noted at Colon. Similar check comparisons for subsequent months have shown that no important errors are thus introduced. Bold-face figures for May, 1902, indicate interpolations, all records being lacking for this month.

Outflow from the Basin above Bohio

Although measurements to determine the discharge of the Chagres at Gamboa and at Bohio were by no means neglected by the en-

Table 29.—Outflow, in Cubic Metres per Second, from the Basin of the Chagres

Month	Basin above Bohio							Basin above Gamboa						
	1898	1899	1900	1901	1902	1903	Means	1898	1899	1900	1901	1902	1903	Means
January	160	109	60	42	318	46	122.5	122	99	48	29	148	46	82.0
February	48	49	30	28	59	29	40.5	42	27	23	19	45	26	30.0
March	31	28	21	20	36	18	25.7	29	27	15	13	29	20	22.2
April	57	31	20	16	61	16	33.5	52	30	16	13	55	20	31.0
May	76	58	46	65	**58**	43	57.6	70	54	38	50	**51**	43	51.0
June	95	89	81	79	90	72	84.3	81	70	55	58	82	61	67.8
July	186	112	159	90	86	114	124.5	120	80	95	62	85	94	89.3
August	150	162	149	122	96	155	139.0	117	120	101	81	79	123	103.5
September	91	120	135	164	111	161	130.3	72	90	87	103	83	133	94.7
October	143	140	198	179	168	158	164.3	98	96	128	105	125	112	110.7
November	222	150	187	375	189	236	226.5	147	106	115	191	134	162	142.5
December	81	102	106	130	85	297	133.5	65	75	76	89	62	199	94.3
Means	112	96	99	109	113	112	106.8	85	73	66	68	81	87	76.6

	Basin above Alhajuela							Basin Alhajuela-Gamboa						
January	....	90	45	28	120	32	63.0	....	9	3	1	28	14	11.3
February	....	24	23	19	36	24	25.2	....	3	0	0	9	1	2.6
March	....	24	15	13	23	14	17.8	....	3	0	0	6	6	2.8
April	....	25	16	13	48	16	23.6	....	5	0	0	7	4	3.2
May	....	45	38	44	**40**	37	40.1	....	9	0	6	**5**	5	5.0
June	....	61	44	49	62	55	54.2	....	9	11	9	20	7	11.2
July	....	63	62	56	60	88	65.8	....	17	33	6	25	5	17.2
August	...	93	80	69	66	90	79.6	....	27	21	12	13	33	21.2
September	....	68	61	83	67	79	71.6	....	22	26	30	16	54	27.6
October	...	75	91	78	91	78	82.6	....	21	37	27	34	34	30.6
November	....	83	84	135	89	139	106.0	....	23	31	56	45	23	35.6
December	....	64	65	86	52	155	84.4	...	11	11	3	10	44	15.9
Means	....	60	52	56	63	67	59.5	....	13	14	12	18	19	15.3

	Basin Gamboa-Bohio						
January	38	10	12	13	170	0	40.5
February	6	22	7	9	14	3	10.2
March	2	1	6	7	7	0	3.8
April	5	1	4	3	6	0	3.2
May	6	4	8	15	**7**	0	6.6
June	14	19	26	21	8	11	16.5
July	66	32	64	28	1	20	35.2
August	33	42	48	41	17	32	35.5
September	19	30	48	61	28	27	35.5
October	45	44	70	74	43	46	53.7
November	75	44	72	184	55	74	84.0
December	16	27	30	41	28	98	40.0
Means	27	23	33	41	32	26	30.4

gineers of the old Company, they have been made with much more system since the work devolved upon the Receiver, and later upon the New Company. The chief stations have been Gamboa and Bohio and finally Alhajuela. As a result, a definite knowledge has been secured of the monthly discharges at the two first-named stations since January, 1890, and at Alhajuela since January, 1895, except for a few months when the work was suspended.

The method adopted for gauging the stream, and for computing the mean monthly volumes, has been fully described in Chapter V.

Table 29 exhibits in cubic metres per second the average monthly discharges for which corresponding rain records are available. The outflowing volumes from the three subbasins are estimated from those measured at the three gauging stations, or rather from the differences between them.

Evaporation, Plant Absorption, and Percolation

There being no natural lakes in the basin of the Chagres, no attempt has been made to measure evaporation from exposed water surfaces. A study of all available records where the conditions are approximately similar led the *Comité Technique* of the New Panama Canal Company to adopt, as the probable evaporation from the projected artificial lakes and the water surface of the canal, 6 millimeters (0.24 inches) per twenty-four hours, adding for possible infiltration an equal amount.

In Nicaragua, where evaporation is an important element in the problem of water supply for a canal, careful measurements were made by the Isthmian Canal Commission of 1899-01, both by the methods of pans floating in the lake and by comparative studies of lake level as affected by rainfall, inflow, and outflow through the channel of the San Juan River. The conclusions are thus summed up from the report of Mr. A. P. Davis, the hydrographer of the Commission:

Observations by the pan method were made in 1898, 1899, and

1900, some of them covering an entire year. The results ranged from a maximum of 8.13 inches in April, 1898, to a minimum of 2.02 inches in September, 1899, the grand average for ninety-four months being 4.28 inches per month, or about 0.18 inch in twenty-four hours. He notes that the results were rather discordant, and, moreover, that the conditions affecting the pans did not duplicate those affecting the lake, where: "Except along the eastern shore the surface of the lake is thrown into billows, the waves often attaining a considerable height and being crowned with whitecaps, and the total water surface in contact with the wind is much greater than the level surface of the lake. Most of the lake surface must, therefore, lose by evaporation a greater depth of water than the pan." Recourse was therefore had to the second method, based during the dry seasons of 1900 and 1901 on the observed lake level, the rain records at eight stations, the estimated inflow, and the measured outflow by the San Juan River. The results in inches per twenty-four hours were as follows: For February, 1900, 0.21; for March, 0.22; for April, 0.18; for first half of May, 0.21. For the second year (1901) the figures were, in February, 0.12; in March, 0.13; in April, 0.26. The grand mean was thus found to be 0.19 inch in twenty-four hours, which, it will be noted, is slightly less than that assumed by the *Comité Technique* for the basin of the Chagres (0.24 inch), but is in good accordance therewith.

What is specially involved in the present problem is not evaporation from exposed water surfaces, but that from the general surface of the basin. Existing data in tropical regions are insufficient to permit a numerical estimate of the latter, but it is well known that the essential elements upon which it depends are the relative volume of aqueous vapor already held in suspension in the atmosphere, the capacity for which is largely increased as the temperature rises, the greater or less agitation due to winds, the absolute atmospheric pressure acting inversely, and the nature of the surfaces presented to the air. The known conditions existing in the basin of the Chagres render it fair to assume that evaporation there must be extremely uniform throughout the rainy months of the year, and that it cannot be excessive in amount. Thus, the hygrometric observations at Colon made by the old Canal Company in 1881, and those by the United States Weather Bureau in 1898, concur in indicating a relative humidity ranging within narrow limits from 0.80 in the dry months to 0.87 in the rainy season. The winds of the Isthmus are gentle, rarely attaining a velocity of 10 miles an hour. The surface of nearly the entire region is covered by a dense tropical growth impenetrable to the rays of the sun or to rapid movements of the atmosphere. The barometric pressure is so nearly uniform that continuous observations covering four and a half years at Alhajuela show an extreme variation of only 0.43 inch, of which about 0.1 of an inch is represented by the normal diurnal oscillation. Finally, the temperature of the air hardly varies from month to month, or from place to place, throughout the entire Isthmus, as has been shown in Chapter IV.

These facts, confirmed by the above measurements of evaporation from water surfaces in Nicaragua, which do not materially differ from similar series under like rainfall in temperature regions, support the assumption that whatever may be the influence exerted by evaporation in the catchment basin of the Chagres, it must be sensibly constant throughout the rainy months of the year and, therefore, will not exert any considerable disturbing influence upon the ratio between downfall and drainage in those months. The same may be affirmed respecting the influence of plant life as it exists on the Isthmus. As already stated, these advantages, together with the absence of ice and snow, greatly facilitate the study of ground water as a function of this ratio, which became one of the special objects of these investigations from its bearing upon possible percolation from the artificial lakes.

Important Bearing of Ground-water Flow

The study of the flow of water in natural channels involves no slight difficulties, as is well known to hydraulic engineers, but the problems offered by the passage through the soil of that part of the rainfall that ultimately finds its way to the sea by that route is rendered far more complex by the variety of the materials to be traversed, and by the addition of two new motive forces to the action of gravity when the laws governing transmission are to be considered. These two forces are capillarity and thermal pressure as affecting both the fluid itself and the more or less compressible materials through which it finds its devious route. Much progress has recently been made by experimental researches on the rate of flow through different materials, but the difficulty of certainly ascertaining the nature of these materials, and the possible existence of fissures impossible to take into account, render too hazardous any attempt to make a practical application of these researches in this particular case. The general fact that water penetrates to depths of perhaps two miles and is in constant movement through the earth's crust has been established beyond question by different lines of investigation, and notably by the fact that some streams increase very sensibly their volume in traversing districts where they receive no visible contributions; but the application of any theory of motion to particular cases has hardly yet been reached in engineering practice.

In the case of the Panama Canal the question of ground water was raised by the claim of the opponents of this route that the creation of artificial lakes by damming the stream might be rendered futile by reason of excessive percolation through the soil to be submerged. The same objection might be raised *a priori* against any proposed reservoir; and the geological formation of the valley of the Chagres offers every reason for believing that no such result is to be apprehended. Nevertheless, since stream flow is a function of rainfall, evaporation, plant absorption, and ground water, and since two of these variables must have nearly constant values in the valley of the Chagres, it seemed possible that a prolonged study of the ratio between the rainfall and the volume flowing in the bed of the stream might throw further light upon the problem. If the result indicated that little or no ground water found its way to the river the possible existence of an underground flow dangerous to an artificial lake would be suggested. If, on the contrary, the volume received through the earth should prove to be considerable, there would remain little or no danger of serious escape from the lakes. The sharp division of the year into rainy and dry seasons would render the study of the ratio decisive on this question. Careful investigations were in progress from January, 1898, to the transfer of the property to the United States in 1904, and as will be shown further on, the evidence is conclusive that no important loss of water from the lakes is to be feared. Ground water has been demonstrated to be a very important element of the volume carried by the river.

Ratio Between Downfall and Drainage

The available data, contained in Tables 28 and 29, have allowed the ratio between downfall and drainage to be studied during a period of six years for the entire basin, for the two subbasins above Gamboa jointly, and for the lower subbasin; and separately during five years for the two upper subbasins. The general formula for the entire basin, taking into account the areas of the three subbasins, is the following, in which the letters *A, C, G,* and *B* denote, in metres, the rainfall at the four observing stations of which they are the initials, *Q* denotes the outflow in cubic metres per second at Bohio, *D* denotes the number of days for which rainfall and outflow are considered, and *R* denotes the desired ratio, *i. e.,* the ratio of the volume of rainfall to that of outflow. The numerical constant correlates the mile and metre units. The computations have been made for calendar months, periods sufficiently long usually to eliminate discrepancies resulting from the time elapsed between precipitation and direct outflow, which observation has shown to vary from twenty-four to forty-eight hours acording to the locus of the rainfall. The formulæ for the separate subbasins are easily derived from the general expression which is the following:

$$(10) \quad R = \frac{Q \times 3600 \times 24 \times D}{1610^2 \left(\frac{250\ (B+G)}{2} + \frac{130\ (G+A)}{2} + \frac{320\ (A+C)}{2} \right)}$$

For making the computations this general expression may be placed under the following more convenient form, in which the unit for *A, C, G,* and *B* remains the metre, and n represents unity for a month of thirty days, 1.034 for one of thirty-one days, 0.934 for one of twenty-eight days, and 0.967 for one of twenty-nine days.

$$(11) \quad R = \frac{n\ Q}{125\ (B+G) + 65\ (G+A) + 160\ (A+C)}$$

Similar reductions may be made for computing the ratio for the separate subbasins. Table 30 represents the results of these several computations applied to the foregoing data. It should be stated that the columns of "means" are not the numerical averages of the ratios for the different years, but are the quotients found by dividing the sums of the corresponding values of the numerator of formula (10) by the sums of the corresponding values of its denominator. The "general average" in like manner is computed from the "means" of the five basins, upon the same principle.

Figs. IX-XIII have been designed to present clearly to the eye the relative values of the more important data pertaining to the hydrology of the basin of the Chagres above Bohio and above Gamboa, and of the three subbasins. These are the monthly variation in average temperature, rainfall, outflow, and ratio between the two latter. The radius of the circle indicates 30° C. of temperature; 500 millimeters of rainfall; 250 cubic metres per second of outflow and a ratio of unity between the rainfall and outflow, both expressed in cubic metres per month. The figures plotted are as follows: Temperatures, from grand means of all the observations at Alhajuela to

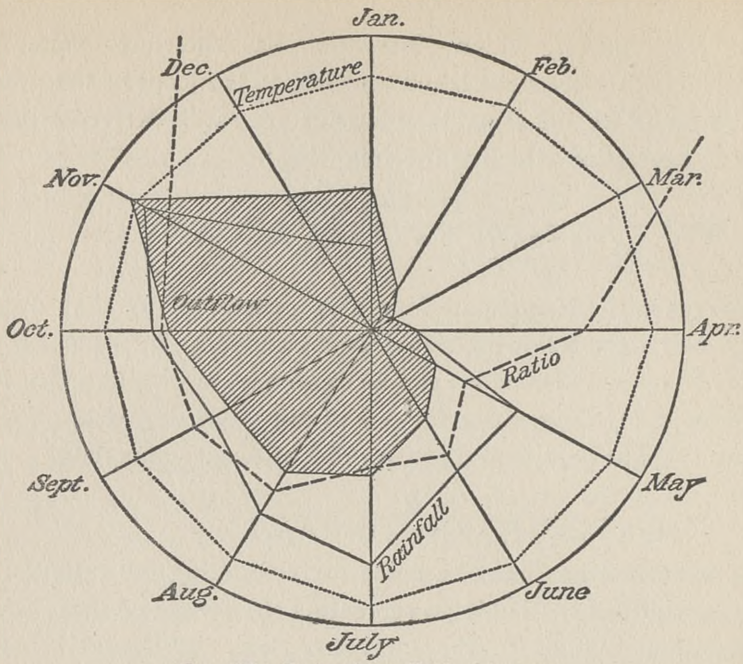


FIG. IX. Basin above Bohio, six years.

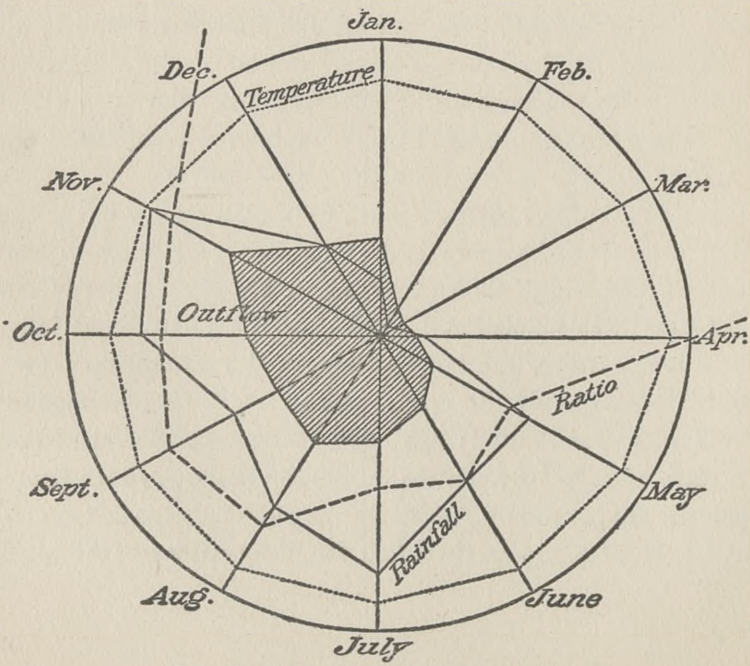


FIG. X. Basin above Gamboa, six years.

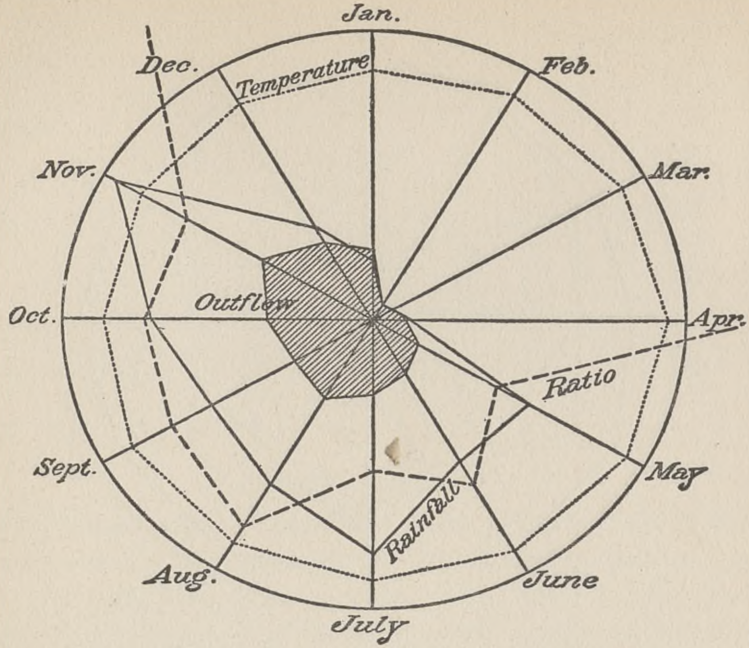


FIG. XI. Basin above Alhajuela, five years.

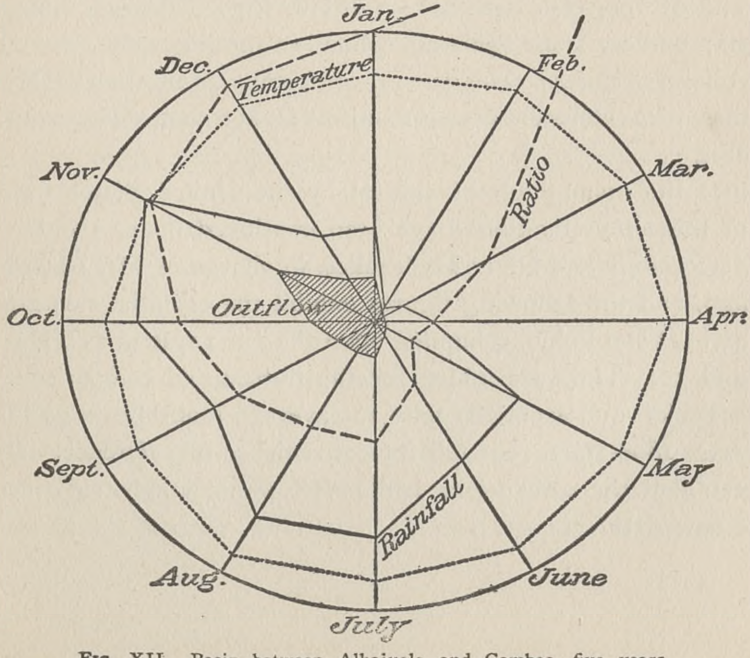


FIG. XII. Basin between Alhajuela and Gamboa, five years.

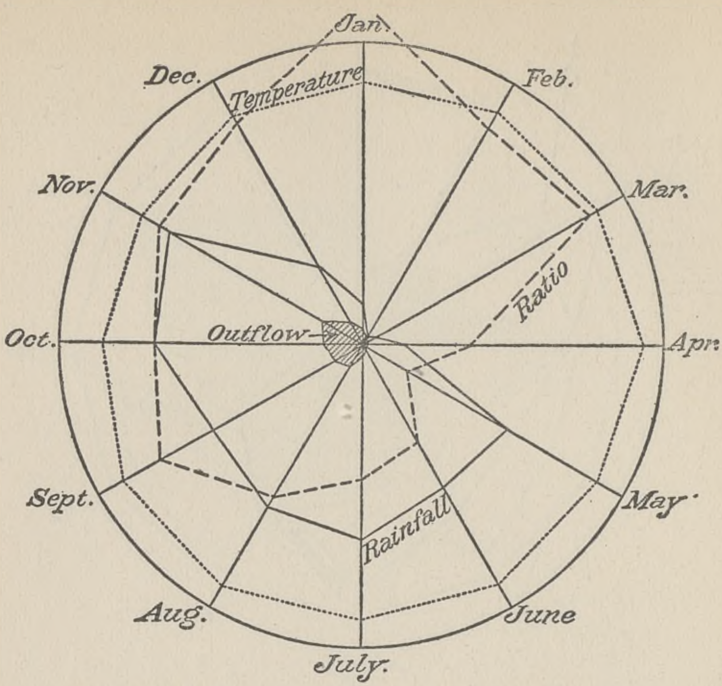


FIG. XIII. Basin between Gamboa and Bohio, six years.

the end of 1903 (51 months); rainfall, from Table 28, column of means; outflow from Table 29, column of means; ratio, from Table 30, column of means. The general conformity of the curves throughout the entire catchment area is manifest from a comparison of the five Figures.

Since the assumption of control by the United States (May 1, 1904) these investigations have been continued under the Division of Meteorology and River Hydraulics, in charge of Mr. Ricardo M. Arango, and the following figures exhibit the essential elements for the basin above Bohio, computed upon the same system as Tables 28, 29, and 30. They are added for the purpose of comparison with those Tables, and especially with the average monthly ratios for the six years 1898-1903, repeated for convenience of reference. It will be seen that the conclusions which follow are amply sustained by these new data.

RAINFALL, OUTFLOW, AND THEIR RATIO, IN BASIN ABOVE BOHIO

Month	Rainfall, millims			Outflow, met. cub.			Ratio, downfall and drainage			
	1904	1905	1906	1904	1905	1906	1904	1905	1906	Aver. 1898–1903
January	124	167	26	139.5	56.4	34.4	1.72	0.52	2.05	1.26
February	28	12	21	65.6	30.0	23.1	3.53	3.38	1.52	2.33
March	44	22	16	39.6	22.4	17.3	1.39	1.50	1.65	1.24
April	279	51	134	102.9	19.3	26.9	0.55	0.56	0.30	0.65
May	264	449	243	81.3	80.6	58.8	0.45	0.27	0.37	0.32
June	360	204	295	128.3	75.6	68.9	0.52	0.55	0.34	0.44
July	282	188	487	118.2	55.5	167.2	0.63	0.47	0.52	0.46
August	219	358	447	85.0	102.6	172.7	0.58	0.44	0.58	0.58
September	354	207	295	176.8	104.5	146.0	0.73	0.75	0.73	0.65
October	220	350	260	129.4	197.2	110.0	0.90	0.87	0.68	0.68
November	433	241	562	213.8	126.4	240.3	0.71	0.77	0.67	0.75
December	114	181	366	114.5	80.3	351.3	1.54	0.67	1.61	1.14
Year	2721	2430	3152	116.2	79.2	118.1	....	....	....	....

ANALYSIS OF THE DATA

To facilitate a study of these data it has seemed to be desirable to consolidate them, and to present the outflow and rainfall in English units, giving the former in the double form both of cubic feet per second and of the height in inches to which 1 square mile would be flooded by the flow. Under the latter form a direct comparison between the figures for outflow and rainfall, and between the different divisions of the basin can be made, since varying areas are eliminated. This arrangement is carried out in Table 31, to which is added for comparison the outflow for as many months as had been well determined at the transfer, together with the ratios as given in Table 30. It should be noted that small discrepancies may exist between the latter and values to be found by direct computation from the rainfall and outflow in inch-miles. They are explained by the neglect of small decimals in the transformation of units, the tabular ratios being correct.

Table 31 reveals numerous important facts as to the regimen of the Chagres. Thus, a comparison between the outflow, expressed in inch-miles, during the period for which corresponding rainfall records are available and during the longer periods for which the outflow only is known, shows a well-marked correspondence through-

TABLE 30.—RATIO BETWEEN DOWNFALL AND DRAINAGE IN THE BASIN OF THE CHAGRES

Month	Above Bohio, six years							Above Gamboa, six years						
	1898	1899	1900	1901	1902	1903	Means	1898	1899	1900	1901	1902	1903	Means
January	1.79	0.99	1.00	3.28	1.10	4.38	1.26	2.83	1.50	1.35	4.29	0.82	7.46	1.91
February	6.33	0.67	7.13	2.50	6.89	7.94	2.33	14.52	5.36	11.12	3.98	8.96	10.66	2.69
March	1.72	0.97	3.50	0.81	1.04	1.62	1.24	3.83	1.88	3.06	0.77	1.59	3.04	1.90
April	0.75	1.26	0.39	0.53	0.54	0.75	0.65	1.48	2.83	0.50	0.60	0.83	1.93	1.06
May	0.47	0.32	0.29	0.30	.....	0.24	0.32	0.70	0.29	0.33	0.39	.....	0.36	0.43
June	0.48	0.55	0.30	0.42	0.70	0.39	0.44	0.12	0.96	0.33	0.43	0.90	0.50	0.57
July	0.48	0.41	0.54	0.47	0.47	0.42	0.46	0.49	0.42	0.48	0.64	0.58	0.48	0.51
August	0.44	0.81	0.71	0.43	0.59	0.65	0.58	0.68	0.95	0.72	0.48	0.89	0.75	0.72
September	0.66	0.58	0.59	0.64	0.59	0.85	0.65	0.88	0.66	0.57	0.67	0.69	1.21	0.80
October	0.65	0.63	0.79	0.59	0.73	0.68	0.68	0.88	0.70	0.82	0.54	0.90	0.76	0.66
November	0.84	0.77	0.65	0.83	0.70	0.71	0.75	0.96	0.79	0.65	0.67	0.74	0.71	0.74
December	0.96	1.32	2.74	1.13	1.05	0.99	1.14	1.14	1.50	3.18	1.51	1.07	1.00	1.16
	Above Alhajuela, five years							Alhajuela-Gamboa, five years						
January	.....	1.90	1.45	4.76	0.94	6.80	1.89	.....	0.53	0.66	1.14	0.54	10.20	1.14
February	.....	0.67	13.42	4.43	8.75	14.24	2.63	.....	0.21	*	*	9.94	1.87	0.79
March	.....	2.35	3.23	0.95	2.15	2.66	2.06	.....	0.72	*	*	0.79	4.97	0.86
April	.....	3.32	0.81	0.80	1.17	1.80	1.27	.....	1.64	*	*	0.13	2.61	0.33
May	.....	0.51	0.43	0.51	.....	0.44	0.46	.....	0.25	*	0.14	.....	0.16	0.15
June	.....	0.99	0.37	0.52	0.95	0.63	0.63	.....	0.36	0.23	0.28	0.79	0.19	0.33
July	.....	0.41	0.43	0.79	0.52	0.62	0.52	.....	0.50	0.62	0.22	0.81	0.10	0.44
August	.....	0.95	0.74	0.58	1.10	0.76	0.79	.....	0.80	0.67	0.22	0.47	0.72	0.56
September	.....	0.68	0.57	0.74	0.76	0.98	0.73	.....	0.62	0.60	0.50	0.50	1.85	0.76
October	.....	0.71	0.78	0.57	0.91	0.76	0.74	.....	0.59	0.91	0.46	0.88	0.72	0.71
November	.....	0.81	0.62	0.61	0.70	0.77	0.69	.....	0.72	0.78	0.84	0.92	0.49	0.74
December	.....	1.49	3.13	2.13	1.00	1.08	1.44	.....	1.51	3.57	0.16	0.93	0.79	0.83
	Gamboa-Bohio, six years							General average of the five basins						
January	0.82	2.26	0.48	2.15	1.55	*	1.00	.....	.....	.....	.....	.....	.....	1.38
February	1.28	1.04	3.27	1.40	2.96	2.49	1.53	.....	.....	.....	.....	.....	.....	1.94
March	2.22	0.07	1.71	0.88	0.44	*	0.40	.....	.....	.....	.....	.....	.....	1.20
April	0.12	0.02	0.21	0.36	0.28	*	0.15	.....	.....	.....	.....	.....	.....	0.51
May	0.10	0.07	0.18	0.18	.....	*	0.11	.....	.....	.....	.....	.....	.....	0.30
June	0.18	0.25	0.27	0.34	0.21	0.17	0.24	.....	.....	.....	.....	.....	.....	0.44
July	0.40	0.38	0.67	0.31	0.03	0.27	0.39	.....	.....	.....	.....	.....	.....	0.47
August	0.18	0.57	0.68	0.35	0.23	0.44	0.38	.....	.....	.....	.....	.....	.....	0.59
September	0.34	0.42	0.61	0.59	0.41	0.35	0.47	.....	.....	.....	.....	.....	.....	0.69
October	0.40	0.52	0.75	0.68	0.47	0.55	0.59	.....	.....	.....	.....	.....	.....	0.67
November	0.65	0.73	0.64	1.11	0.63	0.71	0.78	.....	.....	.....	.....	.....	.....	0.74
December	0.59	0.99	2.03	0.73	1.00	0.98	0.94	.....	.....	...	.....	.....	....	1.14

*No outflow from basin, reducing the ratio to zero.

out the entire year, the only discrepancy being for the month of May, and this variation is explained by exceptional freshets which occurred in 1890, 1891, 1892, and 1896. Furthermore, it confirms the inference suggested by Tables 21 and 22 that this region is now passing through an epoch of minimum rainfall and outflow, since the longer periods indicate a larger outflow.

Again, on comparing month by month the known rainfall and outflow in inch-miles, all five basins are in accord in showing a normal variation. To present this more clearly to the eye, it is illustrated by two curves in Fig. XIV. The rainfall is at its minimum in

TABLE 31.—AVERAGE RAINFALL AND OUTFLOW IN THE VALLEY OF THE CHAGRES

Month	Outflow in foot-seconds			Outflow in inch-miles			Rainfall, inches		Mean ratio
	5 years	6 years	14 yrs.	5 years	6 years	14 yrs.	5 yrs.	6 yrs.	
	Basin above Bohio, 700 square miles								
January	4,061	4,327	4,065	6.69	7.13	6.70	5.85	5.78	1.26
February	1,377	1,430	1,546	2.05	2.09	2.30	1.34	1.06	2 33
March	869	908	986	1.43	1.50	1.63	1.37	1.34	1.24
April	1,020	1,183	1,391	1.63	1.89	2.22	2.67	2.95	0.65
May	1,906	2,034	3,986	3.14	3.35	6.56	10.69	10.47	0.32
June	2,903	2,977	4,001	4.63	4.74	6.38	10.51	10.63	0.44
July	3,979	4,397	5,484	6.55	7.24	9.04	14.03	15.51	0.46
August	4,831	4,909	6,160	7.95	8.08	10.15	12.87	14.21	0.58
September	4,877	4,602	5,860	7.77	7.33	9.34	12.18	11.45	0.65
October	5,961	5,802	7,028	9.82	9.56	11.58	14.63	14.21	0.68
November	8,032	8,000	8,592	12.79	12.76	13.70	17.57	17.01	0.75
December	5,086	4,717	7,445	8.38	7.77	12.26	7.26	6.92	1.14
Year	3,742	3,774	4,712	72.83	73.44	91.86	110.97	111.54	......
	Basin above Gamboa, 450 square miles								
January	2,611	2,896	2,657	6.70	7.43	6.80	3.89	3.90	1.91
February	987	1,059	1,228	2.28	2.45	2.26	1.04	0.91	2.69
March	734	784	842	1.88	2.01	2.16	1.09	1.06	1.90
April	943	1,095	1,215	2.34	2.71	3.01	2.46	2.56	1.06
May	1,670	1,801	2,913	4.28	4.61	7.46	10.94	10.63	0.43
June	2,305	2,394	2,907	5.81	5 93	7.21	10.42	10.43	0.57
July	2,935	3,154	3,808	7.52	8.08	9.76	14.90	15.79	0.51
August	3,806	3,655	3,971	9.75	9.36	10.17	12.54	13.07	0.72
September	3,506	3,344	3,757	8.69	8.29	9.32	10.98	10.35	0.80
October	3,989	3,909	4,304	9.95	10.02	11.04	16.18	15.16	0.66
November	5,001	5,033	5,082	12.40	12.48	12.62	17.60	16.89	0.74
December	3,539	3,330	4,873	9.06	8.53	12.49	7.01	6.69	1.16
Year	2,670	2,705	3,130	80.66	81.90	94.30	109.05	107.41	......
	Lower sub-basin (Gamboa-Bohio), 250 square miles								
January	1,450	1,430	1,408	6.69	6.60	6.49	6.40	6.61	1.00
February	390	360	318	1.62	1.50	1.33	1.02	0.98	1.53
March	135	134	144	0.62	0.62	0.68	1.52	1.54	0.40
April	77	113	176	0.35	0.50	0.78	2.96	3.35	0.15
May	236	233	1,073	1.08	1.07	4.90	10.20	10.15	0.11
June	598	583	1,094	2.67	2.60	4.89	10.50	10.84	0.24
July	1,044	1,243	1,676	4.82	5.73	7.74	12.38	14.82	0.39
August	1,025	1,254	2,189	4.73	5.79	10.10	12.56	15.35	0.38
September	1,371	1,254	2,103	6.12	5.60	9.39	12.57	11.93	0.47
October	1,963	1,896	2,724	9.06	8.75	12.57	14.24	14.96	0.59
November	3,031	2,967	3,510	13.51	13.25	15.68	16.84	17.09	0.78
December	1,547	1,413	2,572	7.13	6.52	11.57	7.22	6.92	0.94
Year	1,072	1,074	1,582	58.40	58.53	86.42	108.41	114.54	......

TABLE 31.—*Continued*

	Middle subbasin (Gamboa-Alhajuela), 130 square miles								
	Outflow in foot-seconds			Outflow in inch-miles			Rainfall, inches		Mean raito
	5 years	7 years	14 yrs.	5 years	7 years	14 yrs.	5 years	6 years	
January	388	293	....	3.44	2.59	....	3.03	....	1.14
February	92	133	....	0.74	1.07	....	0.94	....	0.79
March	99	129	....	0.88	1.14	....	1.02	....	0.86
April	113	96	....	0.97	0.76	....	2.97	....	0.33
May	177	764	....	1.57	6.78	....	10.63	....	0.15
June	396	746	....	3.39	6.40	....	10.19	....	0.33
July	607	697	....	5.39	6.18	....	12.36	....	0.44
August	749	778	....	6.64	6.90	....	11.89	....	0.56
September	975	993	....	8.37	8.53	....	10.94	....	0.76
October	1,081	1,049	....	9.59	9.31	....	13.54	....	0.71
November	1,257	1,145	....	10.80	9.84	....	14.53	....	0.74
December	558	873	....	4.95	7.74	....	5.94	....	0.83
Year	541	641	....	56.73	67.24	....	98.08	....	......
	Upper subbasin (above Alhajuela), 320 square miles								
January	2,225	2,395	....	8.02	8.58	....	4.25	....	1.89
February	890	945	....	2.89	3.07	....	1.10	....	2.63
March	629	643	....	2.27	2.32	....	1.10	....	2.06
April	833	931	....	2.90	3.25	....	2.28	....	1.27
May	1,416	1,646	....	5.11	5.93	....	11.18	....	0.46
June	1,914	1,945	....	6.67	6.79	....	10.51	....	0.63
July	2,324	2,257	....	8.37	8.15	....	15.99	....	0.52
August	2,811	2,679	....	10.14	9.65	....	12.83	....	0.79
September	2,529	2,384	....	8.82	8.32	....	12.05	....	0.73
October	2,917	2,896	....	10.51	10.44	....	14.25	....	0.74
November	3,744	3,389	....	13.06	11.82	....	18.90	....	0.69
December	2,981	2,926	....	10.75	10.55	....	7.47	....	1.44
Year	2,101	2,086	....	89.51	88.87	....	111.91	....	....

February; begins to increase rapidly in April, when the sun is passing the zenith, moving northward; experiences a light reduction in June, when at the summer solstice the northern limit is reached; passes a first maximum in July or August, about the time of the second zenith passage; and, finally, after a slight reduction in September, when the ascending current of air moves southward from the Isthmus, attains the maximum for the year in November, when the sun is lingering near the winter solstice and the moisture-laden winds from the Gulf of Mexico are sweeping over the Isthmus. The outflow curve on Fig. XIV demonstrates that this annual sequence is by no means reproduced in the outflow from the basin of the Chagres. The minimum for the year occurs in February or

March, and the volume steadily increases until November, with only a slight augmentation to mark the July-August epoch. The explanation of this clearly-defined difference between the two curves must be sought in the ground-water flow revealed by a study of the monthly ratios between downfall and drainage, as will appear below.

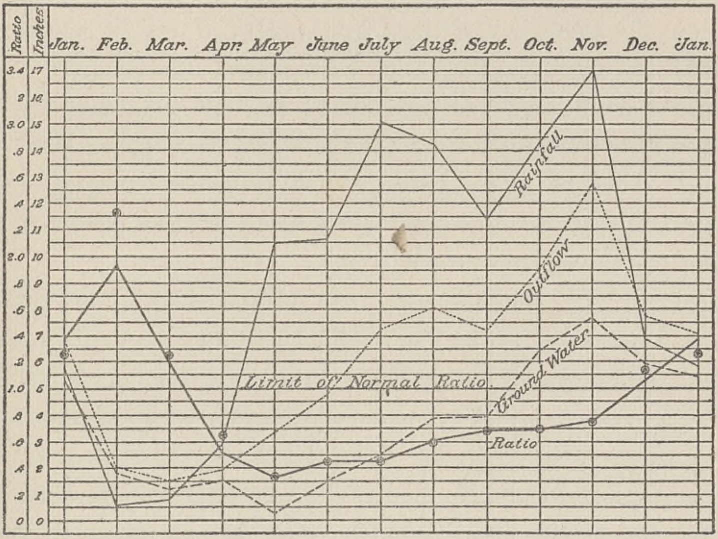


FIG. XIV. Hydrology of the basin of the Chagres river above Bohio. The three curves of mean monthly rainfall, outflow, and ground water are drawn to the scale of inches on the left hand side, and accord with the data given in Table 32. The heavy curve, showing the ratio between the general average rainfall and drainage for the five basins for the six years, is plotted according to the scale of ratios on the left hand side, and accords with the general average given in Table 30.

Before leaving this important Table 31, it is well to note that the annual average rainfall in the three subbasins shows a maximum of 114.54 inches in the lower, a next larger figure of 111.91 inches in the upper, and a minimum of 98.08 inches in the middle or Alhajuela-Gamboa division. Such differences are naturally to be expected from their geographical positions relative to the Atlantic coast and the well-known reduction in rainfall as the Pacific is approached; but on comparing the corresponding outflow, another variation is apparent. The three values of the outflow corresponding to the above rainfalls are, respectively, 4.88 inch-miles, 7.46 inch-miles, and 4.73 inch-miles. This matter will be considered further below.

The ratio between downfall and drainage will now be studied in detail. Except during the dry season, when ground water gives fictitious values exceeding unity, the monthly curves in the five basins are so nearly parallel that the grand mean given in Table 30, exhibiting the average variations from month to month, affords the best basis for a general discussion of this element. A curve representing the final mean has been added to Fig. XIV, with dots to show the corresponding values for the entire basin above Bohio, as given in Table 30. This curve, which is well worthy of study, demonstrates that the same conclusions result whether one or all five divisions of the valley are considered.

Bearing in mind that the maximum normal value of the ratio is unity, corresponding to the hypothetical case that the entire rainfall of each month flows off during that month in the channel of the river, it is at once apparent that ground water plays a most important part in the regimen of the Chagres. The soil of the valley must act like a vast sponge and radically modify the rate of flow. In May, just after the end of the dry season, the ratio has its minimum value, about 0.3, the soil then being probably nearly or quite drained of its reserves. From this date the ratio continues gradually and steadily to increase, indicating a larger and larger volume of ground water escaping to the stream until, in November, when the outflow reaches its maximum, exceeding 12 inch-miles per month, the ratio becomes about 0.75. Then follows the dry season, when the rainfall soon becomes only about 1 inch-mile per month, but the ratio continues to rapidly increase to a maximum, in February, of about two units, indicating that the flow is then maintained almost wholly by ground water. From this maximum the ratio rapidly falls to the minimum, in May, by reason of the gradual failure of the ground-water supply. Thus nature provides reserves to meet, in part, the needs of the canal. This matter is so important that it merits an analysis in figures.

The first step is to form an estimate as to what is the normal ratio between downfall and drainage when there is no flow of ground water. Table 30 presents 23 independent determinations of this ratio for the minimum month (May), giving an average value of 0.30, with a probable error of 0.03. As this value is not inconsistent with what investigations upon other streams of similar size and character of catchment basin would suggest, it will be adopted for the Chagres. While nothing is better established than that this ratio is subject to considerable variations, even in the same district, dependent upon whether the rainfall is gradual or comes in violent downpours, and

TABLE 32.—MEANS FOR SIX YEARS IN THE BASIN ABOVE BOHIO, 700 SQUARE MILES

Month	Rainfall Inches	Measured outflow		Outflow due direct rainfall		Outflow due ground water	
		Foot-seconds	Inch-miles	Foot-seconds	Inch-miles	Foot-seconds	Inch-miles
January	5.78	4,327	7.13	1,030	1.70	3,297	5.43
February	1.06	1,430	2.09	184	0.27	1,246	1.82
March	1.34	908	1.50	22	0.36	886	1.14
April	2.95	1,183	1.89	231	0.37	952	1.52
May	10.47	2,034	3.35	1,907	3.14	127	0.21
June	10.63	2,977	4.74	2,029	3.24	945	1.50
July	15.51	4,397	7.24	2,873	4.72	1,524	2.52
August	14.21	4,909	8.08	2,540	4.18	2,369	3.90
September	11.45	4,602	7.33	2,124	3.38	2,478	3.95
October	14.21	5,802	9.56	2,501	3.16	3,301	6.40
November	17.01	8,000	12.76	3,200	5.10	4,800	7.66
December	6.92	4,717	7.77	1,241	2.05	3,476	5.72
Year	111.54	3,774	73.44	1,657	31.67	2,117	41.77

upon other causes, it may be hoped that in this case observations have been continued for a period long enough to effect mutual cancelation among the variable elements to an extent sufficient to justify general conclusions from the following computations. Nothing more is claimed for them.

Upon the assumption then that in the valley of the Chagres the normal value of the ratio between downfall and drainage, when there is no flow of ground water, is 0.30, the portion of each monthly outflow attributable to direct rainfall may be computed, since it is the product of the measured monthly outflow by the quotient obtained by dividing 0.30 by the observed value of the ratio for the corresponding month. The difference between such outflow and that directly measured will represent the volume attributable to ground water. Table 32 exhibits the results of such a computation applied to the mean outflow past Bohio during the six years recorded in Table 31. If 0.3 should be considered too small a value for the normal ratio when no ground water is flowing, it should be borne in mind that the only effect of an increase would be to reduce the estimated volume of the latter without affecting the essential fact that it constitutes a real and very important element in the regimen of the Chagres. For example, if the normal ratio be assumed as 0.5, which is probably excessive for this heavily wooded region, the computed volume of ground water in November, the maximum month, will only fall from 4,800 cubic feet per second to 2,666 cubic feet, and the corresponding volume of direct flow will only increase from 3,200 cubic feet to 5,334 cubic feet. Such a change has no important bearing upon the fundamental fact of the real flow.

On Fig. XIV will be found a curve showing from month to month the volume attributed to ground flow as contained in Table 32. It is reasonable to suppose that the gradual and progressive filling and emptying of the subterranean reservoir, as rainy and dry seasons succeed each other, should cause a gradual progressive flow of ground water of like character, and this the curve certainly indicates. It may, therefore, be fairly claimed that it offers intrinsic evidence of its approximate accuracy. A comparison of dates shows that the rainfall during these six years attained its maximum in November and its minimum in February, and that the corresponding values of the ratio between downfall and drainage (Table 30) occurred respectively in February and May, or three months later in each case. Furthermore, the rate of increase of this ratio from month to month is less rapid at first than later, as would naturally be expected to result from the prolonged dry season during which the accumulated supply is slowly finding its way to the river bed. These facts perhaps suggest that the average rate of flow through the earth may be such as to require about three months to attain the river.

Finally the results of the analysis certainly demonstrate how groundless are the apprehensions that serious leakages may occur in the artificial lakes which form a part of the project. Manifestly, if important drains other than the bed of the river existed no such normal flow of ground water throughout the entire region is conceivable. The opinions of the geologists of the Company are amply confirmed.

Other Applications of the Ratio

A well-founded knowledge of the ratio between downfall and drainage in the valley of his stream is of no little value to the hydraulic engineer, since it is useful in solving many questions which arise in the progress of his work. Two examples in point will be stated.

Ignoring ground water, and assuming that the value of the ratio determined for each month is applicable to each day of it, it is easy to ascertain the time which elapses between the fall of the rain and its passage past Bohio in the bed of the river. By placing D in formula (10) equal to unity, solving with respect to Q, and reducing, it may be put under the following form:

$$(12) \quad Q = 6750\, R\, (0.6\, B + 0.9\, G + A + 0.7\, C)$$

Substituting in the second member the measured mean value of R for the given month, and for each day the observed precipitation at the four stations, in metres, the deduced daily values of Q will represent in cubic metres per second the volume of the daily rainfall that ultimately passed to the sea at Bohio. The sum of these volumes for the entire month will of course be identical with what was measured at Bohio. By platting each set of daily values and connecting them, the two curves will indicate to the eye the desired intervals of time between the fall from the clouds and the passage past Bohio.

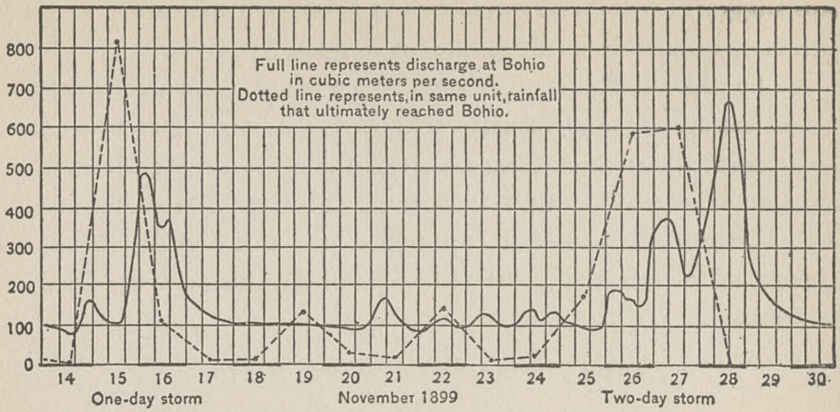


FIG. XV. Retardation of rainfall before reaching Bohio.

With a view to obtain precise knowledge as to the interval of time of which use might be made, telegraphically, during critical periods in the construction of the dam at Bohio, such a daily study was made during an entire rainy season, and the retardation proved to vary from 24 to 48 hours, according to the locus of the heaviest downfall in the basin. Figure XV has been added to illustrate the method; it makes very apparent the influence exerted by the longer or shorter duration of the storms. One or two days will cause a considerable freshet, but the great floods come only with long continued downpours.

The second application of ratio between downfall and drainage, to be cited here, has a bearing upon an important problem of the canal.

That a moderate percolation exists through the lower part of the tertiary deposit that fills the ancient gorge at and above Bohio is well known, and it is not without interest to consider what light this analysis throws upon its importance. Table 31 supplies the data. By regarding only the annual means, all complications resulting from ground water are eliminated; and as outflow per inch-mile and rainfall in inches are directly comparable, conclusions may be formed from a simple inspection of the figures, which are here repeated for convenience of reference.

Locality	Annual outflow, inch-miles			Annual rainfall	
	5 years	6 years	14 years	5 years	6 years
Above Bohio	72.83	73.44	91.86	110.97	111.54
Above Gamboa	80.66	81.90	94.30	109.05	107.44
Lower subbasin	58.40	58.53	86.42	108.41	114.54
Middle subbasin	56.73	....	....	98.08	....
Upper subbasin	89.51	....	....	111.91	....

While it is to be regretted that the observations at Alhajuela were not begun sooner, this evidence is sufficient to justify the belief that the largest rainfall and the largest outflow per square mile occur in the upper subbasin which nearly approaches the Atlantic coast. In the middle subbasin they appear to be the least, as might be expected since it is the one most remote from this rainy coast. But the lower subbasin, although receiving about the same rainfall as the general average throughout the entire basin, and more than that above Gamboa, has a less outflow per square mile than either. The latter district is the better standard of comparison, since the deficiency of outflow in the lower subbasin affects the average for the entire basin, while the average above Gamboa is not thus reduced, and the slight excess there, in recorded rainfall, indicates that the normal outflow of the lower subbasin should be at least equal. But the 5-year column of the table indicates an annual deficiency in outflow of about 22 inch-miles; the 6-year column, one of about 23 inch-miles, and the 14-year column (for which there are no corresponding rainfall data) one of about 8 inch-miles. The area of the lower subbasin being 250 square miles, these figures respectively correspond to discharges per second of 409 cubic feet, 432 cubic feet, and 146 cubic feet, which appear to be attributable to percolation through the bed of gravel underlying the present bed of the river near Bohio. While admittedly of questionable numerical accuracy, these figures are not alarming. They correspond to percolations of 0.06 and 0.02 inch in twenty-four hours, and the *Comité Technique* advisory to the New Panama Canal Company estimated 0.24 inch as the probable percolation from the artificial lakes. Still it must not be forgotten that the flow will be increased under the increased head due to the artificial lake, and in my judgment these new data confirm the belief that the level of a lake created by a dam at Bohio should not be raised to an excessive height, and hence that reserves for the low-water needs of the canal should be stored in an upper lake above Alhajuela, where they will certainly be secured against leakage.

Conclusions as to Disposal of Rainfall

It remains to consider the general problem of what becomes of the rain that falls on the catchment basin of the Chagres, or in other

Table 33.—Disposition of Rainfall in the Valley of the Chagres

Month	Rainfall inches	Outflow, in inch-miles		Evaporation	
		Direct	Ground water	Inch-miles	Per cent. of rainfall
January	5.78	1.70	5.43	Negative	....
February	1 06	0.27	1.82	Negative	....
March	1.34	0.36	1.14	Negative	....
April	2 95	0.37	1.52	1.06	36
May	10.47	3.14	0.21	7.12	68
June	10.63	3.24	1.50	5.89	55
July	15.51	4.72	2.52	8.27	53
August	14 21	4.18	3.90	6.13	43
September	11.45	3.38	3.95	4.12	36
October	14.21	3.16	6.40	4.65	36
November	17.01	5.10	7.66	4.25	25
December	6 92	2.05	5.72	Negative	....
Year	111.54	31.67	41.77	38.10	34

words, to estimate the volume of the residue after allowance has been made for direct and ground-water flow. This residue is usually classed as evaporation, although it really represents not only evaporation, properly so called, but also water absorbed by plants, much of which is ultimately returned as vapor to the atmosphere, and that part of infiltrated water which penetrates deeply into the earth and is there consumed in the chemical changes in progress. The data available are insufficient to render it possible to differentiate between these three kinds of loss.

Table 32 is in a form to facilitate this study, and from it are extracted most of the items in Table 33, which represents the entire catchment basin above Bohio during the six years for which complete data are available. The residue found by subtracting direct flow and ground-water from rainfall is denominated evaporation, which is classed as negative when the outflow becomes greater than the rainfall, by reason of ground-water.

It is to be noted that the monthly estimates for evaporation in Table 33 are subject to the criticism that the ground-water flow due to rain falling in previous months is included in the computations for each month, and must vitiate the results. If the rate of flow through the ground were definitely known this error could be corrected, but this is a refinement too uncertain to be attempted. The steady decrease in the percentage column from month to month in the rainy season is doubtless due to this cause, and the value for June and July, when there is little ground-water, is, say, about 55 per cent., which is probably quite closely the average for the entire rainy season. The average value for the year, 34 per cent. of the rainfall, is not vitiated by ground-water, as it represents a complete cycle, and its small figure is due to the small amount of surface water to be evaporated in the dry season. The reduced humidity then observed confirms this view.

It would appear, therefore, from this study of the rainfall above Bohio, that the annual loss by evaporation (as above defined), averages 3.18 inch-miles per month, corresponding to a flow from the entire 700 square miles of 1995 cubic feet per second, to compare with 1657 cubic feet of direct flow and 2117 cubic feet of ground-water flow. In other words, of the entire rainfall about one-third disappears, another third flows off directly by the channel of the Chagres, and the remaining third, after a retardation of perhaps three months by its passage through the soil, ultimately reaches the bed of the river as ground-water.

Furthermore, the 3.18 inches lost monthly by evaporation correspond to a daily loss of 0.11 inch; and as this applies to the general surface of the country, not to water surfaces directly exposed to the atmosphere, it is in good accord with the measurements (0.19 inch) above quoted made by the Isthmian Canal Commission of 1899-01 in Nicaragua where the climatic conditions are quite similar. Such figures certainly show that the high humidity observed on the Isthmus is easily explained, notwithstanding the large capacity for moisture in air of such high temperature.

To enable a comparison to be made between these results and those noted in more temperate regions, advantage is taken of the summary for 12 American streams given in the able paper on the "Relation of Rainfall to Run-off," by George W. Rafter, which

TABLE 34.—AVERAGE ANNUAL RAINFALL, OUTFLOW, AND EVAPORATION IN THE CATCHMENT BASIN

Streams	Years observed	Catchment area	Rainfall	Outflow	Evaporation
		Sq. miles	*Inches*	*Inches*	*Inches*
Muskingum River	8	5,828.0	39.7	13.1	26.6
Genesee River	9	1,070.0	40.3	14.2	26.1
Croton River	23	338.8	49.4	22.8	26.6
Lake Cochituate	38	18.9	47.1	20.3	26.8
Sudbury River	26	78.2	46.1	22.6	23.5
Mystic River	18	26.9	44.1	20.0	24.1
Neshaminy Creek	16	139.3	47.6	23.1	24.5
Perkiomen Creek	16	152.0	48.0	23.6	24.4
Tohickon Creek	15	102.2	50.1	28.4	21.7
Hudson River	14	4,500.0	44.2	23.3	20.9
Pequannock River	9	63.7	46.8	26.8	20.0
Connecticut River	11	10,234.0	43.0	22.0	21.0
Chagres above Bohio	6	700.0	111.5	73.4	38.1

forms "Water Supply and Irrigation Paper," No. 80, of the United States Geological Survey, 1903. The available data respecting these streams were not sufficient to permit a quantitative estimate of the ground-water flow, but Mr. Rafter in his general summary of the subject states the following conclusions, which are amply confirmed by the Chagres record: "When rainfall is below the mean for several months ground-water may be expected to become continuously lower, with the result that the flow of streams will be less." And, "The ground-water must be taken into account in order to understand all the peculiarities of flow. A very important effect of forests is in increasing the ground-water flow." The preceding table is abstracted from that on page 99 of Mr. Rafter's paper, the unit being inches per square mile of the basin. The figures for the Chagres are repeated for convenience of comparison.

In round numbers, therefore, it appears that the valley of this tropical river has about 2.5 times the rainfall, about 3.3 times the outflow, and about 1.5 times the evaporation characteristic of the northeastern portion of the United States, and that ground-water probably plays a much more important part in the regimen of the stream.

CHAPTER VII

ENGINEER PROJECTS FOR THE CANAL

Although several outline projects for the canal have been formulated upon data more or less authentic since the collapse of the de Lesseps Company, the only studies which seem to call for serious analysis here are those of the New Panama Canal Company, of the Isthmian Canal Commission of 1899-01, and of the Board of Consulting Engineers appointed by President Roosevelt in 1905. These will be considered in turn, in order of date.

As is known to every one, the original project undertaken by the old Panama Company contemplated a sea level construction, but this was changed during the prosecution of the work (temporarily it was claimed) to a canal with locks and a dam at Gamboa. Under the régime of the Receiver, the *Commission d'Etudes* submitted a new provisional project for a canal with locks, stating however that further examinations on the ground were needful before a well-grounded plan could be elaborated. This duty devolved upon the New Company, and has been performed in the most thorough manner. Nothing was taken for granted. An able staff of engineers was employed, headed by M. Louis Choron and assisted by the International *Comité Technique,* whose names and professional standing are given in Chapter I. Years were devoted to a conscientious study of a problem analogous to but not identical with that presented to the United States, and the conclusions have received careful consideration by those upon whom the construction of the canal has finally devolved.

The object in view was a commercial canal suited to meet the needs of such ocean shipping as would use it, not only at present but also in the future. Well known limitations are imposed on this class of vessels. They do not sail regularly from one first class port to another, as do the great European and American liners. Their dimensions must conform to the requirements of the commercial ports of the world where their business will call them. For a private company to expend vast sums to secure dimensions for the waterway in excess of the real demands of trade would be an extravagance far from judicious. The New Company communicated with the great constructors of ocean steamers, and with the leading shippers of the world, as to the desirable dimensions to be given to the waterway to meet present demands and those for the next half century, and the canal was planned accordingly,—with provisions at the locks to permit a reasonable increase subsequently, during the operation of the canal, if this should become desirable in the future. Furthermore, as the old Company had nearly completed a canal at sea level as far as Bohio the problem for the New Company, simply to complete the enterprise, began logically at that point. From the present point of view the conditions are different. A canal constructed by the American government should provide for the passage of the largest ships of the future, which naturally would demand an increased waterway; this difference should be borne in mind in considering the project of the French Company, now to be described.

Project of the New Panama Canal Company

Leaving out of consideration the question of health, there are two principal difficulties to be encountered—the excavation through the continental divide, and the regulation of the Chagres River whose valley the route must follow throughout the greater part of its course. The former involves no serious engineering problem, being simply a removal of a large body of material. The latter must be judiciously planned, taking into account both the control of the violent oscillations of the stream and also the low water supply of the canal because the natural flow in the three dry months is insufficient to meet the needs of a canal with locks. As a sea level canal was recognized as visionary after a close technical study of the problem, this question of water supply became one of primary importance. In fine, then, the project should involve the selection of a summit level demanding no needless excavation, with corresponding provisions for controlling the irregular flow and impounding the needful reserves. These conditions were met neither by the final plans of the old Company nor by the provisional plan of the *Commission d'Etudes.*

The studies of the New Company were based on three fundamental principles: (1) To reject any plan that did not, independently of considerations of time and expense, offer every guarantee of a serviceable canal. (2) To reject any fanciful scheme depending on the application of new and untried devices not justified by experience: and (3) To give due weight to the peculiar tropical conditions under which the work must be executed. These must compel the employment of a class of laborers inferior to those available in better climates, and the work will be exhausting to directors and agents supervising the constructions. No technical details should therefore be admitted involving operations of exceptional difficulty.

The results of the investigations upon the spot had demonstrated to the satisfaction of the engineers of the New Company, that the excavations could be carried safely to any depth suitable for a canal with locks; and that the nature of the subsoil at Bohio, in accordance with the third of the above principles, should bar the adoption of any greater level for Lake Bohio than about 20 metres (66 feet), above sea level. This fixes the level of the bottom of the route for shipping in Lake Bohio, and hence the lowest desirable level in the deep cut, at about 10 metres (33 feet) above mean tide.

Furthermore, an elaborate study of the discharge of the Chagres in its great floods led to the conclusion that provisions should be adopted for impounding at such times about 250,000,000 cubic metres, and for restricting the outflow of Lake Bohio to about 1,200 cubic metres per second as a maximum volume. But the area of

Lake Bohio at a level of 20 metres above tide is about 6,000 hectares (23.5 square miles), which is inadequate for so large reserves. Hence to retain the needful volume a second lake becomes necessary at some point above the point where the river joins the route of the canal. The old Company had selected Gamboa as the site of a dam for this purpose, but the *Commission d'Etudes* had decided that this location is "one of the most unfit that can be chosen," and the examinations by the New Company had developed the fact that a much better one exists at Alhajuela, some ten miles above, where the topography lends itself admirably to the construction of a masonry dam that will meet all demands. The low water reserves will there be safe from losses by infiltration, and flood reserves may be retained varying from about 100,000,000 to 150,000,000 cubic metres according to requirements of the summit level adopted. The area flooded by the dam will be about 3,000 hectares, or about eleven and a half square miles at the height of the low water reserves, and 13.5 square miles at extreme flood height.

In determining the most judicious height to be given to the summit level to fulfill the above conditions, the engineers of the Company were in duty bound to give careful consideration to the financial questions involved; and one of the most important was the probable time of construction, because when so large a work approaches completion the interest cost on sums already expended becomes very large, and the need of a return for the outlay becomes urgent. Great attention was naturally devoted to this matter. No less than sixteen elaborate studies were made before deciding upon the summit level with a view to balance the time and costs between deeper cuts on the one hand and larger dams and more locks on the other,—always keeping the lifts of the latter within limits imposed by experience, which were considered to be about 10 metres (33 feet). The result of this study was to narrow the question to two summit levels, of which the bottom of the canal was respectively 20.75 metres and 9.75 metres above mean tide (68.1 and 32.0 feet).

The respective costs of construction, liberally estimated from actual experience, were so nearly the same (about one hundred million dollars) that the choice could be based on other considerations. Here entered the time element. It was confidently believed that the dam, locks, and outlets at Bohio (where the longest delays were to be expected), and the cut through the continental divide as well, could be completed in ten years if the higher summit level were preferred; but to complete the larger excavations required for the lower summit level within that time was not so certain. It was largely from anticipations of possible delays, involving increased interest costs and possible difficulties in connection with the time limit of the concession from Colombia, that the *Comité Technique* formally approved the higher summit level in its published report dated November 16, 1898. This body remained in session until July, 1900, but without making another formal report. The conclusions reached, however, are embodied in the *Notes Techniques* written by M. Choron, the Chief Engineer of the Company, under date of October 1, 1899, and printed in the same year.[1] This matter has been misunderstood even by some who should be better informed. All the engineers of the Company preferred the lower level, and hoped and believed that it might be accomplished within the ten years by the introduction of more modern machinery and methods of work. The later studies were largely devoted to so correlating the two projects that a final decision between them might be deferred for some three or four years without risk of change in what had been accomplished. The *Notes Techniques*, which had the entire approval of the *Comité Technique*, fully discuss, and show on the same drawings, the details of the longitudinal and transverse sections of the two projects, which in truth were simply variants of one and the same adopted plan. The final selection between them would be made later, in the light of actual experience after large operations had been resumed.

[1] The text was reprinted in English in the letter of instructions of the Isthmian Canal Commission to the Board of Consulting Engineers, 1905.

Under the new conditions attending the completion of the canal, where cost is of less importance than if the work were to be done by a private company, and where no troublesome exactions as to time limits are to be apprehended from the local government, there can be no question that the low level variant should be preferred, and this variant alone will be considered in the following exhibit of the project of the New Canal Company.

Location of the Canal.—The location of the canal closely follows that adopted by the old Company, which was established with excellent judgment and which permits the utilization of the large excavations already made. In the important element of curvature nothing is left to be desired. This is a detail of primary importance, both as to safety and to economy of time in transit. Experience on the Suez Canal has compelled, since the route was opened to traffic, a costly increase from the original minimum radius of 700 metres (2,300 feet) to 1,800 metres (5,905 feet). On the Panama project the ruling radius is 3,000 metres (9,842 feet), falling occasionally to 2,500 metres (8,202 feet), the minimum being 1,700 metres (5,577 feet) and this latter only for about half a mile in approaching Obispo where the width is sufficiently increased to justify the reduction. More than half the entire distance from ocean to ocean follows straight lines.

Longitudinal Section.—Starting from Colon the water-way carries sea level to Bohio, a distance of 23.9 kilometres (14.9 miles), where two twin locks in flight are encountered, with lifts ranging from 9.75 metres to 10.25 metres (30.7 to 33.6 feet) at minimum and maximum stages of the lake (61.5 and 67.3 feet). The lake forms the summit level of the canal, extending 35 kilometres (21.7 miles) to Pedro Miguel, where a descent would be made by two twin locks in flight with lifts ranging from a maximum of 7.1 metres to a minimum of 6.8 metres (23.3 to 22.3 feet) according to varying water heights. Thence a level 2.1 kilometres long (1.3 miles) extends to Miraflores, where would be encountered a lock to overcome the tidal oscillation of about six metres (19.7 feet) in the Bay of Panama. The maximum lift would be 9.25 metres and the minimum (at high tide) 2.25 metres (30.3 and 7.4 feet). Next follows a tidal level, extending to the docks at La Boca, a distance of 6.7 kilometres (4.2 miles) and thence to the ship anchorage near Isle Perico, a further distance of 6 kilometres (3.7 miles). The total distance from sea to sea is thus about 74 kilometres, or 46 miles.

Cross section of water-way.—The depth throughout the canal is fixed at 9 metres (29.5 feet). Between Colon and Bohio the width at bottom when excavated in earth is fixed at 30 metres (98.4 feet) and when in rocky material at 34 metres (112 feet),—the side slopes in the two cases rising 2 on 3 and 3 on 2 respectively to a 3-metre berme submerged 2.5 metres below the water surface. The width at the water level is in earth 63 metres and in rocky material 56.2 metres (207 feet and 184 feet). The minimum wetted cross sections are thus 406.5 square metres and 380.2 square metres 4,375 and 4,092 square feet). Two passing places are provided between Colon and Bohio, with bottom widths of 60 metres (197 feet) extending 600 metres (1.968 feet). Much excavation by the old Company in this section is serviceable.

In Lake Bohio considerable excavation was done by the old Company, but some is still needed. The cross section contemplated for the ship channel is the following: The width at bottom in earth sections is fixed at 50 metres (164 feet), with side slopes of 2 on 3 rising to the natural bottom of the lake. In rocky material the bottom width is 53 metres (174 feet), with side slopes of 3 on 2 rising to same level. Ignoring the enlargement due to lake water on the sides these dimensions give minimum water-ways of 571.5 and 531 square metres respectively (6,151 and 5.716 square feet.)

Throughout the cut of the continental divide, between the waters of the Chagres and those of the Rio Grande, the bottom width is fixed at 36 metres (118 feet), with side slopes and submerged bermes revetted with stone to a point above wave wash. At higher levels with intervals of about 8 metres (26 feet) these slopes are cut by horizontal bermes from 5 metres to 3 metres in width (16 to 10 feet), to favor drainage. The intermediate rises receive slopes suited to the local material. The general upward slope is thus about 45 degrees, more or less, the wet section being about 4,100 square feet.

From the continental divide to Miraflores the cross section adopted does not differ practically from that indicated between Colon and Bohio, the only variation being in the height of the submerged bermes, to adjust them to slight variations in the water level.

From Miraflores to the landing at La Boca the bottom width is retained at 30 metres (98 feet), but the side slopes are reduced to 1 on 5, largely increasing the water-way. Thence through the bay to the ship anchorage near Isle Perico the bottom width is increased to 50 metres (164 feet) to facilitate navigation.

The locks.—Twin locks of equal dimensions are provided at each change of level. Excellent sites exist for all of them. They are five in number, arranged in flight by twos at Bohio and Pedro Miguel, and singly at Miraflores. At each locality, both for entering and leaving the locks, basins are provided having a width at bottom of 62 metres (203 feet) and a length of 700 metres (2,297 feet), with a gradual reduction to normal width in the next 100 metres (328 feet).

Each lock will have a clear length of 225 metres (738 feet), and a width of 25 metres (82 feet). One of each of the twin locks will have an intermediate gate reducing the clear length to 130 metres (426 feet) for use with small vessels. Single pivot gates are favored. The water level in the lock chambers is regulated by channels passing round the gates in the side walls, and debouching on each side by pipes laid in a sunken trench, having perforations extending the whole length of the chamber. The escape pipes are of cast iron 9 feet in diameter, with perforations of about one foot spaced about six and a half feet apart. The water thus flows in and out freely near the foot of the side walls throughout the entire chamber. The discharge is controlled by cylindrical valves operated in the side walls and communicating with the canal above and below.

The locks are to be of concrete, reinforced by cut stone where needful. The minimum depth on the sills is 9.5 metres at the side walls and 10 metres at the axis of the chamber (31.2 feet and 32.8 feet), thus permitting the navigable depth in the canal to be increased to the latter figure, should it become desirable, without change in the locks. Each approach to the locks is to be protected by a substantial structure of piles 16 metres wide and 83 metres long (52 feet and 272 feet), intermediate between the chambers, to assist vessels in entering and leaving.

The cut at the continental divide.—The deep cut at the Culebra has now quite lost the terrors hanging over it in the closing days of the old Company. The excavation at that date was in disintegrated materials near the surface, and serious caving and sliding occurred, partly from natural causes and partly from neglect to secure proper drainage. The old Company made numerous borings, and they have been multiplied by the New Company, with deep pits permitting the material to be inspected to the full depth adopted for the bottom of the canal; some eight million cubic yards have been removed since the resumption of the work, so placed as to secure depth rather than width and thus to throw light on future conditions; and lastly a tunnel 2,100 feet long and 20 feet by 13 feet in cross section has been driven at a low level, without difficulty, at the point where the worst sliding had occurred. All the evidence thus secured concurs in establishing the fact that the dangerous material has already been passed, and that future deep cutting will lie chiefly in an indurated argillaceous schist, traversed by dykes of igneous origin, which stands well even on steep slopes and in which caving is not to be feared. It may be added that the excavation still remaining is exaggerated in popular estimation, the fact being ignored that a large volume has already been taken out. Thus the height of the continental divide on this route is constantly stated at its original figure, which on the line of the axis of the canal was really 345 feet above tide. The narrow bottom of the cut there has now attained a level but little over 100 feet. In fine, the old phantom of a sliding mountain and an impassable continental divide has been definitely laid at rest by the operations of the New Company.

Considering the cut in more detail, it is composed of two sections, known as the Emperador and the Culebra, which are quite different in character. The former, 7 kilometres (4.4 miles) in length, is of moderate depth, requiring the removal of about 18,700,000 cubic metres (24,460,000 cubic yards) of material. The latter, 3 kilometres (1.9 miles long, demands 12,700,000 cubic metres (16,612,000 cubic yards). Indeed the locus of maximum difficulty, lying between points 54.1 and 55.3 kilometres from Colon, and only about three-quarters of a mile in length, is what will cause the greatest delay in execution and which, therefore, demands the closest study. The above volumes refer to the low variant project of the New Company, and represent what was required about five years before its works terminated in April, 1904. During these years work was prosecuted, with moderate activity, in the narrow but deep cut denominated the cunette.

These facts make it clear that to complete the work as soon as possible the point of attack would be this length of three-quarters of a mile, and that here every effort should be made to gain time. Elsewhere haste would be of less importance. Indeed, since the deeper grows the cut the less labor and plant is it possible to employ, and since for many reasons it is desirable to make as few changes in the personnel as practicable, there is a certain advantage in having places ready to receive any surplus plant. Hence the conclusion was reached that logically the work should be planned on this basis. Furthermore, this method would simplify the forming of a well-grounded estimate of the total time required to cut through the continental divide.

The deep cut, or cunette, made by the New Company lies on the westerly side of the great excavation at this locality, so that work on a large scale would take the form of widening eastward through a homogeneous mass. All the spoil would be transported either to the northerly dump at the Lirio or to the southerly dump at the Mallejon, distant three or more miles apart. Any general plan of operations would therefore deal with two problems,—how locally to concentrate work in extending the cut eastward from the cunette, and how to provide for running the trains to and from the dumps without interference and without needless shifting of rails.

In his *Notes Techniques* M. Choron, the Chief Engineer of the New Company, elaborates the plan he formed, and illustrates it by two complete drawings. Various modes of excavation, including wire rope transmission, have been tried at different localities on the cut, but at the Culebra he gives preference to the type of excavator with an endless chain of buckets (ladder dredge) that worked so successfully on the Manchester and Kiel Canals, served by dirt cars of about 7.5 cubic yards capacity. They have already been largely used on the Isthmus, and the laborers are familiar with their operation.

M. Choron proposes to divide the great cut, 4,000 feet in length, into four equal sections, and to operate from the two ends in a manner to reduce the four headings successively to levels, or benches, of uniform heights above the sea. These benches to rise in steps four metres (13 feet) apart, determined by the heights at which the excavators will operate to the best advantage,—whether in raising the material to the cars from below or in excavating it from above the horizontal bench on which rest the tracks of the machine, and two tracks for the cars (one when loading and the other when going to or returning from the dump). The largest number of elevators permitted by the local width of the section to work simultaneously, would vary in number from one to five. The drawings accompanying the *Notes Techniques* explain details.

They show the execution of the work to a level 20 metres (65 feet) above the sea. Sixteen phases are contemplated, each representing 4 metres (13 feet) in height carried across the entire cut. Each transition is marked by the needful shifting of plant, and begins when it becomes possible to start work on the next lower bench.

The problem of the transportation to the dumps comes next in order. To avoid as far as possible the shifting of track, the lines are made permanent beyond points fixed by the condition that the grades on the temporary branches from the excavation shall none of them exceed one and a half or two per cent. On each of the permanent portions is placed a shifting station, where are sidings and facilities for transferring the locomotives from train to train so as to pull or push as may be most convenient. These stations on the two routes leading to the Mallejon dumps are at 46.6 metres (153 feet) above tide those at the Lirio dumps are less favorable, being of necessity at 70 metres (230 feet). The topography here will compel all material to be carried to the Mallejon dumps after a level of about 55 metres (180 feet) has been reached. The latter will be serviceable until a level of about 25 metres (82 feet) has been attained; afterward the material will have to be raised mechanically, either before or after loading on the cars. It will be remembered that the bottom of the cut is 9.75 metres (32 feet) above tide. The details of M. Choron's plan were studied for the higher variant of the project adopted by the New Company, but they throw light upon the rapidly increasing difficulties as the depth of the cut becomes greater. His time estimate, based on experience already had on the work, was nine years, one of them for revetting the navigable channel. Full details of this estimate are given in his *Notes Techniques.* His opinion is that, while the plan of operation may be varied, the estimated time can hardly be reduced. It is his hope and belief that improvements in machinery will permit the low level variant to be completed in about the same period.

M. Choron's time estimates are based on the following figures, resulting from careful studies of the actual work done at the Culebra. Working continuously for 10 hours per day an excavator would take out 760 cubic metres (994 cubic yards) measured in place, or 1,200 cubic metres (1,570 cubic yards) measured in bulk. But the spoil must be transported to the dumps, and an allowance of 40 per cent. in time for shifting trains must be made accordingly, which reduces the volume from 760 to 456 cubic metres (596 cubic yards). Even this must be still further reduced for loss of working time during the seven months of heavy rains, which experience has shown to be about 25 per cent., and also for delays incidental to the complicated system of operating the trains. Thus the final estimate for the effective daily volume, attributable to an excavator during the entire year, becomes only 340 cubic metres (445 cubic yards), measured in place.

This study of the local conditions make it evident that the prompt completion of the cut at the Culebra lies not so much in extreme efficiency of the excavating machines as in the rapidity of transporting the material to the dumps. The frequent shifting of tracks under the heavy rainfall which prevails during seven months of the year, aggravated by the weight of the locomotives, causes derailments and other delays. The early completion of the Alhajuela dam, permitting the electrical transmission of the water power there developed, would dispense with the use of steam at the cut and thus serve an excellent purpose.

The works at Bohio.—These would consist of the dam, the spillway, and the four locks. They are the most important group of constructions of the canal and would demand nearly as much time as the great cut at the Culebra.

The dam projected at Bohio connects Cemetery Butte on the right bank with Bohio Butte, where are located the locks, on the left bank. Both buttes are of rocky material well suited to serve as abutments to the dam. Numerous borings in the bed of the stream demonstrated that the rock on both sides sloped rapidly until a depth was

Empérador Cut in Rainy Season

attained considered unsuitable, in this tropical climate, for the processes needful to secure foundations for a masonry structure. The material overlying bed rock is of ancient tertiary formation, consisting of a thick bed of compact sandy clay underlaid at considerable depths by a less favorable mixture of gravel and sand. This ancient deposit, which is characteristic of the entire vicinity to be flooded, was considered to be very suitable to serve as the foundation of an earthen dam. Some percolation through the lower strata might occur, but not enough to endanger the safety of a dam of moderate height, say of sixty or seventy feet, especially as it might be controlled if found desirable by ordinary engineering methods. Such conditions, however, should fix a limit to permissible water pressure and hence to the height of the dam. Excellent locations far removed from the dam site are available for spillways. One on the right bank would discharge over rock into a diversion of the Chagres on which considerable work had been done by the old Company. The other, still more favorable, is on the left bank near the headwaters of the Gigante River, some three miles away. This would discharge over rock into the swamps of Peña Blanca and Agua Clara, whence a reasonable volume could be diverted to the sea without annoyance to the canal. These conditions suggested the following project:

The dam, with crest at 23 metres (75 feet) above mean tide, to rest on a bed of compact sandy clay at 5.5 metres (18 feet) below the same datum. The thickness of this bed averages about 18 metres (60 feet). The length of the dam at the level of dead low water in the river, which is that of mean tide, is 290 metres (951 feet), and at the crest is 392 metres (1,287 feet). The material throughout to be of the excellent sandy clay abundant in the vicinity, well tamped and revetted on the up-stream side with stone laid in cement mortar on a slope of one on three, interrupted by 4 four-metre bermes suitably disposed; and on the down stream side with dry stone on a general slope of two on three. The toe on the up-stream side to be reinforced by a concrete wall, laid between sheet piling, 8 metres (26 feet) wide and rising from excellent material below to a height of 4 metres (13 feet) above mean tide. To guard against serious damages in case of overflow during construction, the lower part of the down-stream side to a height of 14 metres (46 feet) above mean tide, would be protected by a substantial dressing of large rocks, abutting upon piling placed about 15 metres (50 feet) below the dam. The width of the dam at top to be 15 metres (49.2 feet) and at bottom 139 metres (456 feet). The head of water at highest lake level would be 20.5 metres (67 feet), and at lowest level, 18.75 metres (61 feet).

This construction was approved unanimously by the *Comité Technique,* as meeting all the requirements of the case; and the fact that Mr. Fteley Past President of our Society of Civil Engineers, whose experience in dam construction had been second to none in the United States, cordially concurred with his colleagues in this opinion, should have weight with American engineers. The difficulty of successful damming the Chagres at this locality has been unduly exaggerated by opponents of the route, as will appear further on.

The spillway problem would involve no engineering difficulties, as the topography is highly favorable. The only question lies between an automatic system of regulation over a fixed weir, or a system admitting of control, like that of Stoney, which has operated so successfully on the Manchester Ship Canal. The former, although the more simple, entails the danger of flooding the lower valley, and all the engineers of the New Company preferred the latter, as has been explained in Chapter V when discussing the regulation of the floods.

The location selected for the locks on Bohio Butte is admirably suited for the four contemplated, but there is not room for a third pair in flight. This conditions imposes another objection to an increase in lake level,—that of excessive lifts.

It remains to consider how the works at Bohio should be constructed to avoid damages and delays from so variable a stream as the Chagres. It is fortunate that exemption from them may be confidently expected during the three or four months of the dry season. The following was the plan of the New Company.

The cut for the locks through Cemetery Butte had been executed to a considerable extent by the old Company. The natural crest which rose to a height of about 53 metres (174 feet) above sea level, had been reduced to about 13 metres (43 feet). This would be lowered, ultimately, to the full width required for the twin locks (73 metres or 290 feet), to a level of 3.5 metres (11 feet) below mean tide for the upper locks, and to 12 metres (39 feet) for the lower locks; but it would be sufficient at first to leave a sloping bottom at about tide level. This would provide a channel through which the flow of the river would be diverted by a small temporary dam, leaving the site of the permanent dam dry to facilitate the preparation of the foundations. At the same time work would begin at the spillway site at the headwaters of the Gigante, where the introduction of the system of regulated overflow of which the Stoney weir is a type would call for a crest at a level of 14 metres (46 feet) above sea level. Bed rock is here found at a level of 9 metres (30 feet), and a cut to that depth would make a second diversion of the river, which when the permanent dam had attained about this height, would permit work on the locks to be resumed. Barring excessive floods these arrangements would allow the work on the permanent dam and locks to proceed under exceptionally favorable conditions and even if such accidents should occur the mass of rock on the down stream slope would probably prevent serious injury. Such in brief was the general plan of operations, concerning which full details will be found in M. Choron's published *Notes Techniques.*

The Alhajuela Dam.—This site is so much superior to that at Gamboa, or to any other between them, that unless the visionary scheme of a sea level canal be contemplated there can be no question that it should be preferred for the necessary upper lake. The dam would be of concrete masonry founded on bed rock, and the needful materials except cement are at hand. The principal dimensions are the following, heights referring to mean sea level which in this vicinity is 28 metres (92 feet), below dead low water of the river:

Length of dam at top	285.5 metres	(938 feet)
Width of dam at top	6 metres	(19.7 feet)
Width at bottom	51.5 metres	(169 feet)
Height at crest	71 metres	(233 feet)
Height at roadway	70 metres	(230 feet)
Highest lake level	68 metres	(223 feet)
Low water reserves	65 metres	(213 feet)
Minimum lake level	58 metres	(190 feet)
Bottom of foundations	19 metres	(62 feet)

The dimensions of cross section are liberally computed to allow a moderate increase of height if found desirable; the volume held in reserve in the lake would be augmented at the rate of thirty million cubic metres per metre of rise for such increase. The volume reserved for low water needs of the canal is 170 million cubic metres. The reserve for flood regulation is 100 million cubic metres for the high level variant, and 150 million for the low level variant; but no increase in the height of the dam is required to accommodate the latter, as the supply of the feeder (needful in the former) compelled a higher point of efflux than would be used in the latter, and this would permit the lake to be drawn down to a lower level than indicated above.

There are no engineering difficulties in construction, or in conducting operations at Alhajuela, and as full details respecting them are given in the *Notes Techniques* nothing seems desirable here. The same may be said of the locks at Pedro Miguel and Miraflores.

The above gives a sufficiently complete idea of the project for the canal elaborated by the engineers of the New Company, to permit an opinion as to its merits. The estimated costs of construction, $103,-000,000, based so far as possible upon actual experience on the Isthmus, are carefully computed for the dimensions above indicated, with liberal allowances for contingencies. Some of these dimensions would be subject to modification as the work progressed, but the use of improved machinery would probably cause a reduction of unit prices in the future, and the valuation may be taken as a maximum. The following are the more important unit prices, including labor and transportation of materials.

Dredging, 3 francs and exceptionally 3.5 francs per cubic metre (44 to 52 cents per cubic yard).

Excavation in earth 3.5 francs per cubic metre (52 cents per cubic yard).

Excavation in rocky material 5.5 francs per cubic metre (81 cents per cubic yard).

Excavation in the deep cut varies from 3.5 to 5.5 francs per cubic metre (52 cents to 81 cents per cubic yard) according to locality.

Masonry for the locks and spillways 50 francs per cubic metre ($7.38 per cubic yard).

Masonry for the Alhajuela dam 60 francs per cubic metre ($8.85 per cubic yard).

Project of the Isthmian Canal Commission

The total length of the canal is increased to 49.09 miles by extending the dredged entrances to the six fathom curves. In the Bay of Limon the cost of this extension is estimated at over eight million dollars, and a sharp curvature is introduced having a radius of 3,281 feet.

The waterway throughout the entire distance is given a depth of 35 feet, for the reasons that the time of completion is of less vital importance than for a private company, since the cost of financing would be much diminished if the United States should provide the funds, and that, in a plan prepared for a government seeking the permanent development of its possessions and content to receive its returns in an indirect way and at a future time, the canal must have dimensions which will permit the passage of the largest ships now afloat or likely to be constructed. For a time such ships may be exceptional and the canal revenue derived from them may be small.

In order to make a fair comparison of the different routes suggested for an Isthmian Canal, a uniform scale of dimensions was adopted for the waterway. The following quotations set forth those applicable to the Panama route:

"The bottom width of 150 feet which has been adopted for the canal sections of the Isthmian routes, gives a ratio of width to depth of 4.3 which is slightly greater than at the Suez, Manchester and Amsterdam canals, but considerably less than the enlarged Amsterdam canal will give."

"The side slopes of the Isthmian canal sections vary with the materials. In soft earth or sand they are taken 1 on 3 below water and 1 on 2 above water; in firm earth, 2 on 3 below a berme 10 feet wide 6 feet under water, and 1 on 1 above such berme. The 1 on 1 slopes are to be protected by paving from the berme to 6 feet above water. In rock the sides are vertical from the bottom to a berme 5 feet above water, with slopes of 4 on 1 in hard rock and 2 on 1 in soft rock above such berme, the berme being of such width that the extended slopes would intersect the bottom of the canal at the foot of the vertical sides. In several places a slope of 1 on 1 is used, as in the Culebra cut, on account of the peculiar nature of the material. Where the material is liable to disintegrate in water, as in the Culebra cut, retaining walls are provided, taking the place of the vertical sides of rock cuts."

"Where channels are excavated in open water and the sides will be submerged, the width is made greater. In Panama Bay the bottom width is to be 200 feet, with side slopes of 1 on 3, but at mean tide the width 35 feet below water will be 260 feet and at high tide 320 feet. In the artificial harbor at Colon it will be 500 feet with turning places 800 feet wide."

"The channel widths above given are for straight sections. On curves of less than 12,000 feet radius, in channels less than 500 feet wide the width is increased at a rate of 1 foot for each 200 feet reduction of radius, the widening on a curve of 6,000 feet radius being 30 feet."

"The locks are to have a clear length of 740 feet and a width of 84 feet between the side walls. The depth over the head wall and over the miter sills at the lower end of the locks, which fix the available depth for ships, is to be 35 feet, the same as in the prism of the canal. The miter sills at the head of the locks are placed 1 foot lower, the slightly greater safety thus afforded for these sills being secured by merely exchanging 1 foot in height of gate for 1 foot in height of miter sill wall and without appreciable cost. In order to give the required clear length, all single locks and the upper locks of combined systems will be 788 feet long from quoin to quoin. The lower locks of combined systems will be 793 feet from quoin to quoin, the greater length being due to the greater thickness of the cross wall at the middle gates."

The lock gates are to be of steel of the usual miter form, and extra gates are introduced, both to shorten the chambers for small vessels and to serve as guard gates during repairs at the entrances. The walls are extended for the latter purpose, making the extreme length of masonry 1,031.5 feet for a single lock and 1,829.5 for a flight of two locks. Concrete is proposed, suitably reinforced by stone at exposed points. To facilitate passage a vertical approach wall 1,200 feet long is provided on one side of the canal at each end of every lock or flight.

As was done by the engineers of the New Company, two locks in flight are projected at Bohio and at Pedro Miguel, with a tidal lock at Miraflores; but the aggregate lifts are increased largely, being at Bohio 82 feet for minimum lake level and 90 feet at maximum lake level. At Pedro Miguel they range from 54 to 62 feet; and at Miraflores from 18 to 38 feet.

The spillway projected at the headwaters of the Gigante is of the automatic regulation type, consisting of a fixed weir 2,000 feet in length. With a depth of 5 feet of water on the crest it is estimated that about 78,000 cubic feet per second will escape, and with 7.5 feet about 140,000 cubic feet, and that the latter will more than meet all demands.

With reference to the Bohio dam the Commission states: "In its preliminary report the Commission based its estimates on a masonry dam. The examinations of the ground had not at that time been completed. So far as they had progressed they showed a site where a masonry dam seemed the most suitable, but it was subsequently found that the depth to rock upon that site was at least 143 below sea level at the deepest part. It was considered best to avoid, if possible, so great a depth of foundation. A site was found a few hundred feet farther down stream where the length of the dam would be considerably greater than at the former site, but the greatest depth to rock revealed by the borings was only 128 feet below sea level. The line runs from a point near the railroad station at Bohio, on the east side of the river, straight across to the rocky hill on the west side. On the east side the rock is at the surface practically from the water in the river to the end of the dam. On the west side the bank above low water is composed either of pure clay or of clay mixed with sand, while below low water are found irregular beds of sand and sandy clay. The physical features of the location admit of the construction of an earth embankment with a heavy masonry core carried down to bed rock throughout the length of the structure. For reasons of economy that type of dam is preferable to one wholly of masonry upon the new site, and is now adopted."

"It is proposed to sink the foundation of the core wall by the pneumatic process at all points where the foundation bed is lower than about 30 feet below mean sea level. This requires the pneumatic process to be used through a length of 1,314 feet, of which about 310 feet is at the maximum depth of 128 feet below the sea level. Where the foundation bed is above elevation—30 coffer dams are to be used. This involves the use of coffer dams through a length of 324 feet, the foundation at sea level being extended 78 feet at the easterly end and 246 feet at the westerly end of the pneumatic work. The coffer dams extend to a height 8 feet above sea level.

Above elevation 8 all operations would be carried on by the ordinary methods of dry work."

"The width of the dam at top is 20 feet, and its total length is 2,546 feet. The elevation of the top is 100 feet above mean sea level, affording a super-elevation of the dam of 8 feet above the highest possible water in the lake and 10 feet above the usual high water. Its total height above the lowest part of the foundation is 228 feet. The earth faces of the dam are designed to have mean slopes of one vertical to three horizontal, and to be broken by three terraces, each 6 feet wide. It is necessary to pave only the upstream face, but it is probable that both faces would be heavily riprapped with rock spoil from the lock excavation near the westerly end. The masonry core is 30 feet thick at and below elevation—30. From that level it tapers to a thickness of 8 feet at top."

"Material for the heavy fill required is found in the immediate neighborhood. The local conditions are such that not less than seven-eights of the work could be completed without interfering with the natural flow of the Chagres. When it becomes necessary for the completion of the dam to divert the river, the unfinished Gigante spillway and, later on, the finished locks at Bohio may be employed as diversion channels. A temporary dam would be required to turn the water through these outlets at suitable stages. This temporary dam may be placed either at the site of the permanent dam and finally be buried in it, or at some suitable point higher up stream. The cost of the Bohio dam is estimated at $6,369,640. This estimate is higher than any which has heretofore been made for this dam. It is possible that before actual construction a better location can be found and the cost reduced. A dam on the French location, with masonry core carried to rock, would contain less than half the material in the dam for which estimates have been made, but for a length of 170 feet the foundation would be deeper than anywhere on the adopted location, the maximum being 146 feet below mean tide."[1]

[1]An elaborate re-examination, including many borings with the diamond

It will be noted that the Commission raised the level of Lake Bohio, and of the summit level of the canal, 23 feet above that proposed by the New Company; and no upper lake was proposed. In other words, no flood regulation was contemplated for the Chagres where it strikes the route for shipping near Gamboa, other than an enlargement of the entrance to the lake to a minimum section of 42,000 square feet, nor for the district below Bohio, except diversion channels with levees to protect the canal rising to a height which "must be fixed from observations of floods hereafter" but which is placed for the purpose of estimate at elevation 25. The cost of completing the construction of the canal was estimated at $144,233,358.

The following were the more important unit prices adopted by the Commission, the volume being the cubic yard:

Removal of hard rock	$ 1.15
Removal of soft rock	.80
Removal of earth, not handled by dredge	.45
Removal of dredgable material	.20
Removal of rock under water	4.75
Embankments and back filling	.60
Stone pitching, including necessary backing (square yard)	2.00
Finished granite	60.00
Concrete in place	8.00

Comparison of the Foregoing Projects

In comparing these two projects the different conditions under which they were prepared should be taken into account. The New Company had only a commercial canal in view. The Company was

drill, was made of these two dam sites between June, 1904, and February, 1905. Designating by C the French location and by F that adopted by the Commission of 1899-01, the following conclusions were reported: "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.....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 (—168.3 feet), 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."

organized to thoroughly study a problem which heretofore had been treated too hastily, and its large staff of engineers devoted nine years to the work. The Canal Commission was formed to study *all possible Isthmian routes,* and the facilities for obtaining full governmental control of the one deemed best for use in time of peace and time of war. Great pressure was brought to bear both by Congress and by the public, for a report at the earliest possible date. The members were appointed on June 10,1899, and rendered the final report on November 16,1901. Less than two and a half years was a short time in which to study such a problem.

The increased dimensions of the projected waterway in the Commission plan naturally resulted from the kind of navigation proposed. In the most permanent element, that of the locks, the increase on that of the New Company was not great, being only 2.2 feet in depth, 2 feet in width, and 2 feet in clear length.

The radical difference lay in the mode proposed for regulating the Chagres River. One was by two lakes, with a limited outflow from the lower, and a reserve supply stored in the upper where it is secure against percolation; the other contemplated a single lake, discharging freely upon the district below, and holding the needful low water reserves subject to percolation, which experience in the New York water-works shows is liable to occur even through a thin core wall. Here other filtration outlets more or less important are believed to exist.

It must be borne in mind that the topography of the country fixes the least height possible for a single lake above Bohio, called upon to regulate the floods of the Chagres and to receive and store the supply needed to meet the demands of the canal in the low water season. This height is about that adopted by the Isthmian Canal Commission, which at normal stages is about 22 feet above that projected by the *Comité Technique.* There are three grave objections to this increase.

The first is that it adds 22 feet to the height through which each ship that passes the canal must be raised and lowered. Furthermore, if, as is suggested by the Commission, the construction of the upper lake may become needful in the future, when it will be too late to correct this evil, why not avoid a permanent defect by making that lake a part of the original project?

The second objection is that the locality at Bohio is not well suited to receive more than two locks in flight, and this has led to the certainly objectionable lifts adopted by the Commission, ranging from 41 feet to 46 feet (usually 42.5 feet) according to the stage of the lake. Mr. Morison, a member of the Commission, shortly after signing the report, read a paper before the American Society of Civil Engineers in which he proposes to reduce them by introducing a new canal level and an additional lock at Tiger Hill. Why not avoid the difficulty by lowering the level of the lake as is done by the *Comité Technique?* Such lifts with their enormous lower gates (83 or 84 feet high) are quite without precedent in a ship canal, and would certainly increase the risks of accidental delays, and even of interruption of traffic. By the project of the Company the lifts would range between 34 feet and 32 feet according to the stage of the lake, the usual being less than 33 feet.

The third objection to this single-lake project arises from the nature of the sub-strata at the site of the Bohio dam. This is a gorge, probably due to the action of some ancient river, which has been filled up to the level of the present bed by tertiary deposits of clay, gravel and sand. The dam projected by the engineers of the Company was of earth resting upon a solid bed of clay and sand that offered a suitable foundation. The borings indicated underlying strata of gravel and sand which might permit percolation to a certain extent, but not sufficiently to endanger a dam exposed to the moderate head contemplated. Such percolation would exert no influence upon the supply reserved for the needs of the canal in the dry season, since this would be held back in the upper lake above Alhajuela where no escape is to be apprehended. By the project of the Commission the conditions are radically changed. About 22 feet are added to the usual head of water, and the security of the reserve held in Lake Bohio for the dry season is endangered by percolation not easily estimated. Hence the Commission considered a masonry core extending to bed rock to be essential, adding enormously to the difficulty of construction and to the cost. Mr. Morison, after signing the report, also reconsidered this dam project, proposing to substitute an earth construction of the type proposed by the engineers of the New Company, but of greatly increased dimensions rising to the same greater height as that of the Commission. In respect to percolation, by making use of recent data concerning sand filtration he arrived at an encouraging estimate of the volume to be apprehended, but it would seem that he overlooked the fact that this permeable stratum lying far below the foundations of the dam, and extending an unknown distance into the region below, cannot be assumed to be affected by raising the water level locally just below the dam, as would be done by his additional canal level extending to his lock at Tiger Hill. Such raising would doubtless reduce seepage through the dam itself, but this is not what is to be feared. So long as the deep route exists for the water to filter to the river or sea below the foundation of the dam, the needed reserve is liable to escape. In Chapter VI this matter of percolation has been discussed from a new point of view, and with the conclusion that storage in the upper lake is to be decidedly preferred.

But these three diffifficulties do not complete the objections to this single-lake project. The dual-lake plan regulates the entire river from the point where it reaches the route for shipping to the sea. With a single lake, the first few miles, where hills contract the waterway, are exposed to the full force of the floods, and of the frequent freshets which during eight months of the year may average two or three per month. The extension of the level of the lake nearly to Alhajuela would have little influence, for the volume unreduced must reach the wide lake, and as the upper part of the submerged district would be very shallow the chief flow would be confined to the deepest portion, which leads directly to the route followed by shipping. It is true that this extension of lake surface nearly to Alhajuela would do much to prevent the introduction of a small volume of silt into the ship channel; but the exclusion of the silt, and of sand and gravel rolled along the bottom as well, will be better effected by transforming the torrential river into a quiet stream of practically uniform flow, as would be done by the upper lake with its outflow regulated as contemplated.

The only merits which are claimed for the higher level incident to Lake Bohio in this single lake project appear to be: (1) a saving of expense in the deep cut through the continental divide, which cannot be established without a complete technical discussion including the relative costs at Bohio and all other items involved; and the studies of the engineers of the New Company indicated nearly equal costs at the different levels contemplated; (2) the reduction in the volume of silt carried by the river to the route traversed by shipping, which as has been shown above is better effected by an upper lake; and (3) the area of Lake Bohio increased to about 40 square miles, thus affording a more convenient basin for the accommodation of shipping in transit. In answer to this latter claim it may be stated that the lake as projected by the *Comité Technique* (about 23.5 square miles in extent) would afford all the space needful for this purpose, and it would appear that there is little advantage in increasing by 70 per cent. the evaporation, and hence enlarging the volume required for canal reserves during the dry season. The greater portion of the added area would be shallow, and much of it would soon be invaded by tropical growth.

In fine, then, the dual-lake project regulates the Chagres throughout the entire valley, giving a canal absolutely free from currents or silt and sand deposits, and at a considerably lower summit level than is possible when a single lake above Bohio is called on to do the work. By it the difficulties of construction of the Bohio dam are greatly reduced, and the objectionable lifts at that locality are brought within the limits of experience. The low-water reserve is secured beyond cavil. It is interesting to note that all the technical objections raised against the Panama route by hostile witnesses at the hearings of the Senate Committee on Interoceanic Canals, in 1902, prior to the passage of the Spooner Act, have more or less force as against this single-lake project, but fail utterly as against the dual plan.

When discussing the problem of regulating the floods of the Chagres, in Chapter V, the matter of regulated or automatic spillways for Lake Bohio was treated at some length. Here it is only necessary to add that as damages to the railroad have usually occurred at such times the matter was carefully investigated by the *Comité Technique,* and the conclusion was reached that overflow should be restricted to 1,200 cubic metres per second (42,380 cubic feet). The sea level approaches so nearly to that of the land in this vicinity that a considerable rise of water surface, involving the flooding of the country, is needful to secure the head requisite to carry off a much larger volume. The automatic-regulation plan admits a volume estimated at 80,000 cubic feet or more to pass in floods. His proposed introduction of a new canal level 26 feet above tide would suggest that Mr. Morison had fears respecting a possible flooding of the lower district and canal. The substitution of a system of movable sluice gates would equally effect the object, and probably at much less cost. Furthermore, the two systems admit of combination.

In fine, it would seem, then, that if the lake area to be traversed by shipping is restricted to the district above Bohio, the topography of the Isthmus demands a second lake, above Alhajuela, to cooperate in regulating the flow in floods and freshets, and to hold in reserve the volume needed for operating the canal in the dry season.

Projects of the Board of Consulting Engineers

The most important consideration from an engineering point of view in projecting a transit route, whether it be a railroad or a canal, is to adjust the details to the topography and natural conditions of the region to be traversed. On the Isthmus of Panama, the Chagres River is the dominating feature. The canal and river must be near neighbors for about three-quarters of the entire distance, and the real problem is to so plan the former as to make it harmonize with the characteristics of the latter in the most perfect manner possible. The deep excavation in the Culebra section is a formidable undertaking, chiefly because it will be necessary to transport the spoil to long distances; but once executed it will remain without giving occasion for anxiety in the future. The Chagres, on the contrary, is capable of becoming a very active enemy at any future time unless effectively tamed by good engineering.

The Board was unable to agree upon a unanimous solution of the canal problem. Two projects were submitted, one of them at sea level with a tidal lock at the Panama end; and the other having a summit level 85 feet above mean tide, created by a dam at Gatun and reached by three locks at that locality, the descent being made by one lock at Pedro Miguel conducting to a second lake 55 feet above mean tide, and thence to the Pacific by two locks at Sosa, near La Boca. Each project will be briefly considered in turn.

There is no radical difference between them at the two ports of entrance, that on the Colon side being formed by a jetty skirting the shore of Manzanillo Island from a point near the mouth of the Mindi, with a short eastern jetty to suitably narrow the approach. The existing canal entrance is thus left to be used as a locus for depots of supply. On the Pacific side the existing anchorage in the Bay of Panama is reached after passing the locks by dredged channels, as heretofore. The general dimensions of both projects are controlled by the language of the law defining the size of the vessels to be accommodated, which are to be "of the largest tonnage and the greatest draft now in use, and such as may be reasonably anticipated." This requirement has largely increased the dimensions of the waterway as contemplated in previous projects. The size of the commercial vessels engaged in general traffic is regulated by the depth available in the important commercial ports of the world, while that of the modern leviathans is limited only by the exceptional depths existing in the great ports between which alone they are designed to ply. The capacity of the new projects thus not only greatly exceeds that afforded by any existing ship canal, but also largely discounts future demands for increased facilities.

Both these projects also differ in another important element from those which have preceded them. The cut at the Culebra section, below the top of the indurated argillaceous schist, is projected by the Board on a general slope of 3 on 2 instead of 1 on 1 as adopted both by the New Panama Canal Company and by the Isthmian Canal Commission of 1899-01. This considerably reduces the estimated volume of the excavation, especially for the sea-level project. Whether the nature of the material will justify so steep a slope in the deep cut is left to be verified in prosecuting the work.

Both projects were based on the same schedule of unit prices, as follows:

Excavation in dry earth, except in Culebra, cubic yard..........	$0.40
Excavation in soft rock in dry, except in Culebra................	1.00
Excavation in hard rock in dry, except in Culebra................	1.15
Excavation in hard rock in lock pits, below elevation—10.........	1.50
Dredging, mud and sand in Colon and Panama harbors..........	0.15
Dredging, soft material removed by hydraulic pumps, in canal....	0.25
Dredging, indurated and hard clay requiring cutters.............	0.70
Dredging, coral rock..	1.50
Dredging, rock drilled and blasted in dry, to elevation—25........	1.50
Dredging, rock removed under water............................	2.50
Culebra cut, all material without classification above elevation+10	0.80
Culebra cut, all material below elevation+10....................	1.25
Dams, earth borrowed..	0.50
extra for placing material from line of canal within 4 miles..	0.20
extra for placing material from line of canal over 4 miles....	0.25
when placed in dam by pump from barges below elevation+50	0.20
when placed in dam by pump from barges above elevation+50	0.30

Railroad, excavation in earth			0.40
	excavation in rock		1.00
	tracks, including rails, ties, ballast etc	mile	10,000.00
Masonry, concrete		cubic yard	8.00
	granite, cut quoins and mitre walls	cubic foot	3.00
	for copings	cubic foot	2.00
	brick lining for culverts	cubic yard	15.00
Timber, in mitre sills		1,000 feet	100.00
	in permanent cribs	1,000 feet	55.00
	foundation piles, creosoted	linear foot	0.55
Iron, structural steel		pound	0.075
	cast iron for culverts, mitre sills, with machinery	pound	0.04
	Stoney sluices, 30 feet opening, 15 feet high	each	15,000.00
	Stoney sluices, 50 feet opening, 15 feet high	each	25,000.00
Gamboa or other dam excavation, earth in foundation including coffer dam, temporary dam, and pumping stream not diverted, cubic yard			2.50
Same if stream is diverted			1.00
Same, rock in foundation, stream not diverted			2.50
Same, rock in foundation if stream is diverted			1.50
Diversion channel in earth, cubic yard			0.40
Diversion channel in rock			1.00

The total cost of the sea-level project is estimated by the signers at $247,000,000, and the time of construction at twelve to thirteen years. This estimate of cost is increased to $272,000,000 by the Isthmian Canal Commission in transmitting the Report, and the estimate of time to twenty years.

The cost of the lock canal project is estimated by the members favoring it at $139,705,200, and the time of construction at nine years. The Commission states: "We consider both of these estimates reasonable, subject to the remarks already made concerning unit prices."

These remarks were: "The quantity of each class of work to be done can, as a rule, be accurately measured, but the unit price for each class must be largely a matter of judgment. It is the opinion of this Commission that the unit prices adopted by the Board are, upon the whole, judicious, except in the case of rock excavation under water, which seems to us low, but is accepted here for the purposes of comparison; and that otherwise the estimates are as near an approximation to the truth as can now be reached, in all except two items." These items had no reference to the lock canal project, applying only to that at sea-level.

The sea-level project.—The waterway through the land section is given a depth of 40 feet below mean tide, with a bottom width in earth of 150 feet and side slopes adjusted to the nature of the ground so as to give a surface width varying between 302 and 437 feet. In rock the bottom width is to be 200 feet, and the surface width 208 feet. The least cross section thus slightly exceeds 8,000 square feet. Of the total length of 49.14 miles between deep water in the two oceans, 20.39 miles are to have a bottom width of 150 feet, and 19.47 miles a bottom width of 200 feet.

The curvature throughout is gentle, but for 19 miles a large ship must continuously be changing direction in a channel having a width only from one-quarter to one-fifth of her own length, and which, as will appear below, may carry currents of about four feet per second. On the Manchester Ship Canal all large ships require the assistance of two tugs, one ahead and the other astern, whose sole duty is to aid the pilot in steering; and even then when the wind blows fresh from abeam or astern he finds no little difficulty in keeping off the banks. For the Panama Canal, although a greater width is projected, the increased size of the shipping will aggravate this difficulty, as well as that of vessels passing each other in route; and furthermore on the whole line of the canal there is no point provided where a ship can turn around. Once started the only exit is at the other end; and in case a serious obstruction should occur during the passage of a fleet of war vessels this defect might involve a real disaster. It is true that turning points might be introduced but none appear in the estimates. Such a waterway is far from meeting the conception of free and unobstructed passage popularly associated with a sea-level canal.

It remains to consider how the problem of regulating the Chagres

River is solved in this project. During construction numerous temporary diversion channels are recognized as unavoidable, but as many of them will be subject only occasionally to a considerable flow, and as the constant outlay to keep them free from the invasion of the rank tropical growth would be large, most of them are ultimately to be abandoned. The canal itself is to become the channel through which by far the greater part of the volume of the Chagres must reach the sea. The de Lesseps idea of a still water canal is thus replaced by a narrow regulated river, in which a maximum velocity of about four feet per second at times may be tolerated. The means by which this design is to be effected are the following.

The Chagres River where it first strikes the line of the canal near Gamboa carries about two-thirds of its entire volume at Bohio, which latter in the flood of 1879 was about 112,000 cubic feet per second. This portion, nearly 80,000 cubic feet per second, is to be arrested by an immense dam at Gamboa rising 180 feet above the surface of the canal, distant only about a quarter of a mile. The total length of the crest would be about 6,000 feet, of which 1,000 feet would rise from a level 50 feet below the bed of the river, the excavation being in very permeable sand and gravel. No detailed design for this dam was formulated, and even whether it should be an all masonry structure or a concrete core wall bedded in an embankment formed from the spoil of the Culebra cut was left for future determination. Surveys above the site indicate that the capacity of the lake thus formed would be ample to arrest the largest known flood, and by a system of sluices it is proposed to admit the accumulated volume gradually into the canal at a rate not exceeding 15,000 cubic feet per second. Whether the volume would flow to the Atlantic, or through the Culebra cut to the Pacific, or partly by each route, would be determined by the contributions received at the time from the lower tributaries.

The regulation of the tributaries entering the Chagres below Gamboa is not so simple. Those nearest to the Atlantic are the Trinidad and the Gatuncillo. The former would be confined to the old bed of the Chagres by protection levees bordering the canal for about eight miles above Gatun; the latter, with the other tributaries of the right bank below Bohio, would be diverted by embankments near Gatun into the unfinished French diversion channel conducting to Manzanillo Bay. Above Bohio the problem becomes still more difficult. The volume to be disposed of aggregates about one-third of the total present discharge at Bohio, or in floods, say, about 35,000 cubic feet per second—enough to raise the existing river 23 feet at the low stage. It has been asserted that only in the great floods, which are extremely rare, are such contributions important. This is a mistake. The freshets at Bohio, which often occur two or three times monthly in the rainy season, are not infrequently caused by downpours largely located below Gamboa, so that a dam at that site would fail to restrain them. Such a contingency occurred in October, 1905, shortly after the Board had completed its inspection of the Isthmus. Reference to the tabular exhibit of rainfall in this month, given in Chapter IV, will show in round numbers the following distribution: Cristobal 14 inches, Gatun 21 inches, Bohio 15 inches, Tabernilla 14 inches, Gamboa 15 inches, Emperador 18 inches, Rio Grande 15 inches, while at Alhajuela less than 11 inches fell. There were two moderate freshets of the Chagres in this month, and Table 23 shows an average monthly discharge at Bohio of 6971 cubic feet per second, to compare with 3480 at Gamboa and 2688 at Alhajuela. But these figures hardly do justice to the case. During three consecutive days the flow per second averaged at Bohio 18,153 cubic feet per second, while at Gamboa it was only 7525 cubic feet, and at Alhajuela only 5,074 cubic feet. Table 25 shows that this freshet was of the moderate type, but it suffices to demonstrate that the Chagres River cannot be controlled for the needs of a sea-level canal simply by a dam at Gamboa. The tributaries between Gamboa and Bohio carry important volumes, and it remains to consider how they are dealt with in this project.

The three most important tributaries on the left bank in this district are the Cano, the Gigante, and the Gigantito, all of which enter below Tavernilla about 5 miles above Bohio. Their contributions are to be held back by four dams, forming two great lakes raised to sufficient heights to admit of drainage near their headwaters, one to Pena Blanca swamp and the other to the Trinadad river, both thus returning to augment the volume acting against the canal levees. It it to be noted that time did not admit of detailed surveys for these dams, so that the estimates of cost are based on suppositions. From the best maps available the height above ground of the three largest was assumed to be about 70 to 80 feet, and the aggregate length about 3,500 feet. They were assumed to be of earth.

But these three rivers do not comprise the only important tributaries between Gamboa and Bohio. There are fifteen others which during the nine rainy months are liable at any time to carry considerable volumes, to say nothing of the small drainage channels abounding in a region subjected at this season to a rainfall of over a dozen inches per month. This volume, including the entire contributions from the right bank and all above Tavernilla on the left bank, is to be turned into the canal, causing, with that received from the lake at Gamboa, cross currents, possible erosion of banks, and more or less deposition of sedimentary matter to be removed from time to time by dredging. In the report the maximum velocity of the current in the canal is placed at 2.64 miles per hour, or about 4 feet per second.

Such a route with 19 miles of continuous change of direction, and the difficulties of passing each other superadded, will not be attractive to modern leviathans. The more the problem is studied of how to adjust a sea-level canal to the Chagres River the more difficult does it appear. It is well to recall that since the de Lesseps fiasco the question of the best type of canal has been brought officially before three foreign and one American engineer commissions, aggregating thirty-nine members, to whom should be added M. Choron, the eminent chief engineer of the New French Company, and that without a dissenting voice the decision has been in favor of the lock-type. If the fanciful dream of an unobstructed waterway is to be met, the only alternative appears to be to incur the expense of untold millions in opening a "strait" across the Isthmus, and in depriving the present generation of any benefit arising from its construction. The sea-level canal as projected differs widely from such a conception.

But this project for a sea-level canal does not dispense with a tidal lock. At the Pacific entrance to the canal spring tides have two daily oscillations of about 20 feet, and it was the unanimous judgment of the Board of Consulting Engineers that a tidal lock in duplicate could not prudently be avoided. To admit such tidal waves into a canal already carrying currents was not seriously to be considered. Locks were accordingly projected at a favorable site between Mont Ancon and Mont Sosa, having a serviceable length of 1,000 feet and a serviceable width of 100 feet. It has been claimed that the gates can stand open when the difference between the water level in the canal and in the Bay of Panama does not differ more than a few feet, and hence that such locks will be much less of an obstruction to traffic than those of the normal type. Actual experience at the eastern entrance of the Kiel canal does not warrant this claim. There the usual tidal oscillation does not exceed a foot or two, but in wind storms the level may rise about 10 feet or fall about 8 feet in respect to the normal stand, and it was decided that locks could not be avoided. It was however estimated that they would stand open about 330 days in the year. Actual trial has demonstrated the error of this assumption. Even gentle currents have been found to be dangerous to shipping attempting to pass between the lock walls 82 feet apart, even when moving in opposition to the flow, and much more so when moving with it as the power of steering is then impaired; and the regulations now require the gates to be kept closed. Evidently, as is contemplated by the project, a sea-level canal at Panama, which is virtually a regulated river, must be obstructed by a tidal lock at the Pacific entrance; and what may happen at the Atlantic entrance during the rare occasions of the violent tempests known as "northers" is a matter of conjecture. A great tidal wave entering under such circumstances may work serious damage both to shipping in transit and to the earthen side walls of the canal itself.

The lock canal project.—The waterway of this type, as projected, has strong points of resemblance to that between Lake Superior and Lake Huron, which now carries more than three times the tonnage passing the Suez Canal, and more than the aggregate passing the four great ship canals of the world—the Suez, the North Sea, the Kiel, and the Manchester. The Poe lock alone in September and October, 1905, when the Board was in session, passed 6,622,239 net registered tons. This great St. Mary's waterway has a total length of about 61 miles. The difference of level between the lakes is about 22 feet, of which 20 feet are concentrated at the Sault Ste Marie. This height is overcome by either one of three locks, which were built in the following order; the Weitzel, having a length of 515 feet and a serviceable width of 60 feet; the Canadian, having a length of 900 feet and a width of 60 feet; and the Poe, having a length of 800 feet and a width of 100 feet. It is proposed to replace the Weitzel lock by a new one having a length of some 1,300 or 1,400 feet and a width of some 75 or 80 feet. The canals proper on both sides of the river are simply approaches to the locks from Lake Superior, the length of each being about 1.5 miles. The rest of the waterway is an improved natural extension of Lake Huron, soon to have channels of a minimum width of 300 feet where used by shipping moving one direction only, and a width from 600 to 1,500 feet where traversed by shipping moving in both directions. The present depth is nearly 21 feet, soon to be increased to 25 feet.

The lock project for the Panama Canal contemplates a navigable waterway of this general type, which affords accommodation vastly superior to any that can be constructed in excavation at this locality at any reasonable cost and in any reasonable time. Instead of a relatively narrow channel more or less affected by currents, bank erosion, and sedimentary deposits, unrestricted lake navigation is afforded through a channel never less than 1,000 feet wide for one-third of the entire route. The rest of the distance, except for five miles at the Culebra cut, affords a channel ranging from 800 to 300 feet in width and nowhere subjected even to gentle currents, except for about 4 miles below Obispo in great floods; and even here they will be eliminated when the time comes to build the Alhajuela dam. Throughout the entire waterway between Gatun and La Boca, including the Culebra cut, the normal depth is 45 feet, ranging from 47 to 42 feet according to the stand of the lake, which will never fall below the normal except during the latter part of the three dry months, February, March and April. The total curvature of the route from ocean to ocean is only 638 degrees, and it follows straight lines for 42.4 miles; only 7.3 miles involve changes of direction, and they are made readily in the wide channels which permit the pilot to steer by ranges and choose his own course. The Chagres River is simply and effectively controlled, being received with all its tributaries in an immense lake where currents will be naturally absorbed and where any deposits will be made far from the route for shipping. This liberal increase in sailing width and depth, with freedom from currents, continuous changes of direction, and deposits, will offer attractions to mariners far out-balancing the objection of having to pass a few locks.

The size of the locks has been determined by the language of the law authorizing the canal. The largest ships now existing or under construction are the Mauritania and the Lusitania of the Cunard line, which are 800 feet in length, 88 feet in beam, and 38 feet in draft at the maximum load line. A length of 700 feet and beam of 76 feet may be accepted as the dimensions of the largest commercial ships now in use or building that are likely to traverse the canal. The locks are designed to afford a serviceable length of 900 feet and a serviceable width of 95 feet. With a view to absolute security of operation, the project provides two pairs of gates at the head and two at the foot of each summit-level lock, together with long approach piers and other devices to guard against all possible contingencies; although experience at the St. Mary's Falls canal, where a traffic of 360 million tons net register has passed during the past fifty years without a single accident seriously obstructing navigation, demonstrates how little they are to be feared either for the canal or for the shiping. The chances are as nothing compared with the risks every where encountered from storms on the ocean or even in passenger and freight movements by railroad.

The lake forming the summit level, 85 feet above tide, is created by an earthen dam at Gatun, to which unprecedented dimensions have been given in order to place its safety beyond cavil. Its location near the coast, where the valley of the Chagres for a dozen miles rises very gradually above sea level, favors the formation of a deep lake by a dam of moderate height. A water level of 85 feet at Gatun floods an area of about 110 square miles, affording an enormous reserve for canal operation in the dry season; while at Gamboa the dam must raise a lake 130 feet above the bed of the stream to flood about 33 square miles. At Gatun the dam will rest on a formation of rocky impermeable indurated clay, traversed by two ancient gorges now filled by deposits of the tertiary period. In the larger, this deposit consists of a practically impermeable mixture of fine clay and sand extending to a depth of about 200 feet below mean tide, the width at top being about 1,800 feet and at bottom about 900 feet narrowing to about 100 feet. The cross section is about 25,000 square feet and the borings show no really permeable material. The smaller gorge is 900 feet wide at top, and is filled with similar material to a depth of about 200 feet below tide. The remaining 60 feet contains a stratum of coarser material which may permit moderate seepage; it has a width at top of about 400 or 500 feet, narrowing to a point at bottom. This dubious material has a cross section of about 15,000 square feet. No imaginable percolation through such material as this is, and at such depth, could endanger the safety of an earthern dam properly planned; and any loss of the low-water reserves can, if deemed advisable, be prevented by the familiar process of pumping down cement grout. Furthermore, if it should be thought expedient to do so, by the use of modern sheet piling and other well-known devices, all possibility of sensible seepage can be eliminated. The entire question is simply one of engineering detail to be solved by the chief engineer when the time comes to construct the dam. By far the larger portion rests on ideal foundations.

The only other dams of any importance in the lock canal project are the three on the Pacific coast to form the small lake at that end of the canal. They are to be of earth, like that at Gatun, and call for no detailed discussion. The lock sites are favorable.

The exceptional size of the locks gave special importance to the study of the water supply available during the three dry months; but the ample data collected by the engineers of the French companies, supplemented by measurements made on the Trinadad and the Gatuncillo by the Isthmian Canal Commission of 1899-01, fortunately left no element in doubt. The area of the basin of the Chagres above Bohio is about 700 square miles, and above Gatun about 1,200 square miles. The corresponding lake areas are to be 38.5 square miles and about 110 square miles. The extended series of water measurements conducted at Bohio for seventeen years have made known the volume that the river may be depended on to contribute during the three dry months when alone the natural flow falls below the requirements of the canal. The absolute minimum volume during this long period was 742 cubic feet per second at Bohio and about 1,225 cubic feet at Gatun. Allowing 4 feet in depth over the entire lake surface as a reserve, we have an additional volume of 1,577 cubic feet per second available, affording a total of 2,802 cubic feet per second to draw upon. Part of this must be allowed for unavoidable losses from evaporation, infiltration, leakage at gates, power for lighting the canal and operating the locks, etc. Based upon a careful study of all existing data this volume is estimated at 1,437 cubic feet per second. The difference between 2,802 and 1,437—that is to say 1,365 cubic feet per second—represents the volume which can be expended during the three dry months in lockages. The size and lifts of the locks being known, a little calculation indicates a continuous flow of 52 cubic feet per second as that required to supply the prisms for one transit of the canal. Having 1,365 cubic feet available, 26 daily transits are thus provided for, which would accomodate from 30 to 40 million tons of annual traffic, depending on the size of the vessels. When this limit is approaching it will be needful to provide a dam on the upper Chagres for additional reserves. An ideal location exists at Alhajuela, some ten miles above Gamboa, which is vastly preferable to the latter as a dam site. A design was carefully elaborated by the engineers of the New French Company, of which the cost was estimated at $2,400,000. With a water surface rising 130 feet above the bed of the river, this masonry dam will collect a reserve during the rainy months sufficient to yield a flow of 2074 cubic feet per second for the ninety days of the dry season,—supporting 40 daily lockages more. Obviously there can never be a deficiency of water for any conceivable traffic demands; and by providing additional locks, of increased dimensions if then desirable, future generations can enlarge the passage capacity of the transit route to any desired extent. Indeed at any time slight increases in navigable depth may be made by simply raising the lake levels accordingly, the only cost being that of raising spillway crests, lock walls, and lock gates, lowering the floors of two lower locks, and deepening the harbor approaches, neither operation interfering with traffic. Enlargement of a sea-level canal can only be made by excavating throughout its entire length both bottom and sides, the latter often extending far above as well as below the water surface. It is easy to see which type of canal is most elastic in the way of meeting possible future demands.

It remains to consider the dangers which have been urged against the canal, especially one of the lock type. Fanciful speculations have been advanced suggesting attempts to interrupt navigation either maliciously or in time of war. They seem to be wholly uncalled for. We stand pledged to open the route to the commerce of the world, and by adopting the policy of international agreement to its neutrality, so successful at Suez, all danger of its becoming a battlefield will be eliminated. It is conceivable, however, that in the event of a passage of a fleet of battleships in time of war the hostile nation might plot its interruption, and it is therefore pertinent to consider the relative dangers of such attempts directed against a sea-level and a lock canal. The most vulnerable points are not the locks, sluiceways, and dams, for these occupy but little space and can easily be guarded by a small force. The most ready point of attack would be where a narrow waterway traverses a jungle, favoring the placing of a bag of dynamite where the ship must certainly pass, and where its explosion could be effected either by an automatic mechanical device or by a man concealed in the undergrowth, where he would be little exposed to detection by patrols, and where he could operate a portable electric igniter. Such places abound on the long and narrow route of the sea-level project, but are rare and easily watched on the relatively broad lake route. The risk is distinctly greater for the former than for the latter.

Another danger, unduly magnified at the time of the recent disaster at San Francisco, is that due to a possible earthquake. Fortunately the Panama route traverses a region less exposed to such dangers than any other on the Pacific slope. It lies about midway between the long line of volcanoes extending southward from Colombia and northward from Costa Rica. The latest eruptive rocks of the Isthmus date from the early tertiary period, and what earth tremors are experienced are those transmitted from distant foci of disturbance. That destructive shocks are very rare is attested by the wide flat arch in the old Santo Domingo convent at Panama, which has stood uninjured since the early days of this ancient city.

As a measure of relative danger, it may be noted that seismograph records kept recently for the same forty-four consecutive months at Panama and San Jose de Costa Rica, show four slight shocks lasting ten seconds at the former, and ninety-one slight and thirty-five strong shocks lasting sixteen minutes at the latter. A really formidable earthquake might disturb the adjustments of lock gates, but could hardly effect such an artificial hill as forms the projected dam at Gatun. What it would do to a dam rising nearly 200 feet above its foundations at Gamboa, and sustaining the pressure, it may be, of a head of 130 feet of water behind it, is not so certain. A failure from any cause of this dam, or indeed of any one of the three other high dams on the left bank, which are projected to maintain lakes always full, would overwhelm a sea-level canal with a flood compared with which the disaster at Johnstown would be as nothing.

The occurrence of the disastrous earthquake at San Francisco was seized upon by the opponents of a lock canal as furnishing an unanswerable argument in their favor in the Congressional debate then in progress. The facts now well established by technical investigation demonstrate precisely the contrary. A well marked fault line indicates the locus of maximum disturbance on the San Francisco peninsula. Prof. Derleth of the University of California writes: "One can travel for miles along an almost exact right line and find the ground cracked and disturbed as though some giant hand had run a plow or a knife through it." This fault line lies in the ocean abreast the Golden Gate. Extending in a south-east direction it cuts the Pacific Coast line near Lake Merced and traverses the peninsula, first striking the Spring Valley Water Company's system of water supply for San Francisco along the eastern side of the San Andreas storage reservoir; then passing about two miles to the eastward of the Pilarcitos storage reservoir, separated from it by a range of hills, it follows longitudinally the long and narrow Crystal Springs storage reservoir throughout its entire length. A better practical test of the effect of a formidable earthquake upon a com-

Ancient Convent of Santo Domingo, Panama

plex water supply system could hardly be imagined. The conduits and distributing mains were the only parts that were seriously injured; the dams and accessory structures were left practically intact. The facts in detail are the following:

The dam of the San Andreas Lake is constructed wholly of earth with a puddled core, and sustains the pressure of about 90 feet of water. The fault line touches the eastern end. Prof. Derleth writes: "As an eye witness I am convinced that this dam was subject to a most severe earthquake shock, and since it retains the water of San Andreas Lake apparently just as well as before the earthquake, it should be a source of great satisfaction to its designer and builder. The ground is considerably scarred by cracks running north-northwest on the eastern bank of the dam, where the nose of a hill naturally projects to form its abutment. These cracks, which are quite pronounced, are in the abutment and not in the dam itself. There are a few smaller cracks running in the same direction at the westerly end of the dam. On the roadway of the dam there are some longitudinal cracks, apparently due to the unequal settling of the triangular masses with respect to the core, but they are not serious. The writer is convinced that an earth dam properly constructed will stand a very violent shock."

The Pilarcitos dam is constructed in the same manner, and sustains the same head of water. It was "unaffected" by the earthquake.

At the Crystal Springs Lake, which remained full of water two weeks after the catastrophe, there are three noteworthy dams. The first is an old earth structure which separates the present lake into two parts; it was crossed by the fault but shows no serious injury. The main or "San Mateo" dam is formed of concrete, rising 115 feet above the natural surface. Prof. Derleth writes: "It was subject to a series of thrusts and pulls in vertical planes along its length since it is parallel to the fault line. . . . So far as the writer could see, and he examined the dam carefully, there is not the slightest crack. The intake works, Crystal Springs pumping station, and all accessory construction in the neighborhood of the dam is intact." The third dam which is a smaller concrete structure at Searsville, was also uninjured.

These facts go far to settle the dam, lock, and earthquake controversy for Panama, so far as it is possible to reach a conclusion on such a subject from actual experience elsewhere. It may be added that the recent great Valparaiso shocks were not even registered on the delicate seismographs at Panama.

It is proper in closing to remark that the details of the projects under consideration were elaborated by a study of only about three months, while those of the two antedating them had received years. For the lock project, especially, there may be several variants conforming to one general design. Indeed, an examination of these three projects indicates that properly they all may be so considered. For example, the fundamental element which determines the depth of the great cut is the level above tide of the *bottom,* not of the *water surface,* of the summit level of the canal. This height was assumed by the French Company at 32 feet, by the Isthmian Canal Commission of 1899-01 at 47 feet, and by the Board of Consulting Engineers at 40 feet. So small differences tend to confirm the belief that the general elements have received the attention requisite to develop wise conclusions, and that actual construction may be actively pressed without fear of radical changes hereafter. Meantime it would be well to consider minor variants, some of which indeed have been already suggested by Mr. Stevens.

A brief comparison of the last and the earlier projects may be suggestive. One of the undoubted merits of the former is the extension of the lake to cover the valley below Bohio. This eliminates two objections to the Commission project—lifts of 45 feet at Bohio, and the excessive volume discharged upon the district below, where the canal was to be at sea level. It improves the French project by doing away with the extensive use of regulated spillways and of the necessity for two lakes to control the floods—thus largely increasing the capacity of lake Alhajuela for low-water reserves. Incidentally it renders of no importance the fact that the lock site at Bohio is too short to accommodate two locks in flight having the dimensions called for by the law of Congress.

In view of the vigorous attacks that have been made upon the dam and three locks in flight at Gatun, attention may be invited to the fact that small changes are here possible. By transferring the upper lock to Bohio the flight at Gatun will be reduced to two locks, and the height and dimensions of the dam will be greatly reduced. At the Bohio site there is ample space for a single lock, and a dam there raising the lake above to 85 feet will retain all the advantages of the Board project from that point to the Pacific. The lift will be only about 25 feet, and the counter pressure of the lake below will prevent any important seepage under the dam. Indeed, the latter may be wholly eliminated, if so desired, by familiar methods. The only objection to this modification will be a reduction of storage space for the low-water supply, but computations demonstrate that this may be met practically by an earlier construction of the Alhajuela dam. Another possible variant, which would however involve an increased cost of construction, would be to reduce the summit level to about 65 feet, with one lock at Gatun and another at Bohio, the descent to the Pacific being made by three locks as in the project of the French Company. This would still retain the advantages of the lake below Bohio, raised to a height of about 33 feet only. In a word, the lock solution admits of several variants by which any criticisms raised against the Board project may be readily met if desired.

From the paper issued recently by the Isthmian Canal Commission for the information of bidders, entitled "General Plan for the Construction of the Panama Canal," it appears that the following modifications in the Board project are under consideration, although not finally adopted.

At the entrance from the Caribbean Sea it is not intended at the present time to construct either the breakwater or jetty; and the width of the channel to the mouth of the Mindi River may be increased to 1,000 feet. The material, subject to the approval of the Chief Engineer, may be deposited in the Gatun Dam. Both of these modifications were suggested for consideration by the Board.

Instead of three locks at Gatun, having a lift of 28.33 feet, two locks with a lift of 42.5 feet are under consideration. No estimate of quantities has yet been made for the latter. The size may be increased to 1,000 by 100 feet.

It is possible that the size and location of the regulating works near Gatun may be changed.

Slight increases in the width of the lake channel may be made.

In the Culebra Cut the progress of the excavation may suggest changes in slope and possibly the introduction of masonry revetment in portions of the waterway.

The location of two of the dams forming the lake near Panama has been modified. One will extend from Sosa Hill to Corozal Hill, with a small dam thence to the high ground to the eastward, thus causing the lake to encroach less upon the Panama Roilroad and the environs of the City.

It will be noted that none of these modifications involve important changes in the project as submitted by the members of the Board favoring a lock canal.

LOCK OR SEA-LEVEL TYPE

The action of our Government in finally adopting a lock plan for the waterway might seem to render superfluous any further consideration of a sea-level type of construction; but as the ill-omened conception has greatly retarded the completion of the international highway, and as the above discussion treats only of the special plan last elaborated, a few words on the problem, broadly considered, may not be out of place. The true criterion is ease and safety of transit, and that this test leaves no doubt as to which type of canal should be preferred at Panama is apparent from the following review of the local conditions.

Near Gamboa, where the Chagres first joins the route of the canal, the bed of the river is about 45 feet above mean tide level, and since below that point the old bed, to be occupied by the canal, follows the lowest depression in the valley any new banks must dominate the latter for many miles. In other words, the water near Gamboa would naturally pour into a sea level canal in the form of a huge cascade. Hence there are only three possible solutions of the sea level problem.

(1) The plan adopted by the first French Company was to excavate new beds for the stream and its tributaries from Gamboa to the Atlantic coast. The opening of such channels would not only call for enormous excavations, but also for the construction of gigantic levees for many miles, where the water level must dominate the canal. But such levees confining a river having so torrential a regimen could not but be a standing menace. It needs only to imagine a ship canal constructed parallel to and close behind the levees of the Mississippi, to estimate the slight attractions such a route would offer to mariners. Even with an upper lake or lakes to more or less control the floods of the Chagres, a canal having such neighbors would be much less safe than a lake route, and hence distinctly inferior to one provided with locks judiciously planned.

(2) A sensibly total diversion of the upper river either to the Atlantic or to the Pacific, has been suggested as a second possible solution. Such a plan would involve the abandonment of an excellent dam site at Alhajuela and compel the construction of a huge dam at or near Gamboa where the site is far from favorable. Indeed, this site after careful examination by the the engineers of the New French Company was unanimously rejected by them as unsuitable for a safe dam. Moreover, to convey away so large a volume, which might equal 65,000 cubic feet per second for a period of 48 hours, spillway cuts rivaling the excavation at the Culebra must be

opened, or tunnels of dimensions larger than those of the new double-track railroad under the Alps, must be driven for miles through materials which can only be made certainly known by trial drifts of equal length; and this in a climate where the average temperature throughout the entire year is 80° Fah. Furthermore the Chagres lying in wait behind the Gamboa dam would threaten destruction in case of a break like that at Johnstown, or serious delays in transit in case of any yielding in a long tunnel carrying rapid currents, where repairs would be excessively difficult.

But granting that this second solution is feasible from an engineering point of view, it only meets part of the requirements. Provision must also be made for the disposal of the contributions of the numerous affluents entering between Gamboa and Bohio. Fed by a rainfall greater than on any other part of the canal line, and entering laterally, as many of them must, these volumes would cause cross currents and eddies in the route for shipping never to be encountered in a good canal. Only about half of the discharge at Bohio passes Alhajuela, and only about two thirds passes Gamboa. But to fully appreciate this problem of the lower tributaries a few figures are necessary, and they are given in the following table based upon long and careful observations of the engineers of the French Companies. They show the heights of the natural cascades into the canal to be dealt with, and the approximate volumes in cubic feet per second carried in the dry season, in the rainy season, in the frequent freshets, and in the standard great flood. The last two are naturally the controlling elements. To give an idea of the dimensions required for diversion channels, it may be added that the present channel of the river at Bohio shows a rise of over 20 feet when at the low stage it receives 35,000 cubic feet per second.

These facts would seem to demonstrate that, joined to the enormous excavations required for a canal at sea level, any plan contemplating the total diversion of the Chagres and its tributaries is financially impracticable.

CONTRIBUTIONS BETWEEN GAMBOA AND BOHIO

Affluent	Cascades in feet	Volume in cubic feet per second			
		Dry season	Rainy season	Freshets	Flood 1879
Upper Obispo (K. P. 49)	165	2	16	466	....
Rio Camacho (K. P. 49)	165	2	80	982	....
Rio Mandinga (K. P. 45)	45	5	300	1,500	....
Quebrada Quatra Cales	45	10	50	500	....
Rio Carabali	40	15	150	760	....
Rio Juan Grande	38	15	300	1,200	....
Rio Pisco	34	15	300	1,200	....
Quebrado Culo Seco	40	5	80	300	....
Rio Baila Monos	45	15	153	760	....
Quebrada Caimito Mulato	35	8	80	300	....
Quebrada Agua Bendita	35	8	80	300	....
Rio Caño	33	75	773	3,850	....
Rio Gigante	30	18	185	920	....
Rio Frijoles Grande	26	31	321	1,593	....
Rio Frijolito	20	20	200	1,000	....
Rio Agua Salud	25	19	198	982	....
Quebrada Aojeta	15	20	200	1,000	....
Total normal	....	283	3466	17,613	....
Total, flood 1879	....	....	....	....	34,000

(3) The third solution would contemplate a canal prism large enough to carry to the sea the greater part of the volume of the Chagres and affluents above Bohio, when aided for regulation purposes by a large lake created by a dam at Gamboa and by two lakes on the left bank with outflow through their bounding watersheds. This is essentially the project elaborated by the members of the Board of Consulting Engineers who favored a canal of the sea level type; and it is believed to be the best practical mode of treating the problem. Its drawbacks have been considered above; and it may be safely asserted that its estimated cost disposes of the fanciful scheme of an artificial "strait" involving untold millions more.

In fine, well established facts demonstrate that the conception of a sea-level construction is incompatible with the actual topographical and hydraulic conditions existing upon the Isthmus. Forced upon the first French Company by the commanding influence of M. de Lesseps, a diplomatist and not an engineer, it entailed financial ruin upon his associates. Revived, largely through the efforts of Mr. Wallace, it has caused the loss of precious time since the work passed under the control of the United States. With abundant financial resources and unlimited time for construction, it may be considered "feasible" from an engineering point of view to construct, a sea-level canal, but when completed it must always remain inferior as a transit route to the lake type adopted.

APPENDIX

PANAMA AND NICARAGUA IN 1898

The following article, which first appeared in the *Forum* for November, 1898, but was soon after reprinted as a Congressional document, is repeated here to illustrate how the matter appeared when the contest between the routes was inaugurated in the United States:

The delays and risks experienced in bringing the "Oregon" eastward from the Pacific Coast, at the outbreak of the war with Spain, have drawn the attention of the whole country to the importance of an early construction of a ship-canal across the isthmus now obstructing free communication between our Atlantic and Pacific coasts. The route by Cape Horn is entirely too long to meet present demands, either commercial or military.

But while *a* canal is so urgently demanded, it is equally true that it should be, in respect to facilities of transit, security of operation, and cost and time of construction, *the best canal possible.* The work will be a gigantic engineering feat; and no mistake in selecting the route should be made at the outset.

Unfortunately, the American public has been led to believe, by the collapse of the old sea-level project at Panama, that there is only one really practicable route for a canal; viz., that by Nicaragua. The elaborate investigations which have been in progress at Panama during the past eight years are little known or appreciated in America; having been conducted quietly (especially during the last four years) by the New Company, with a view to determine the best and most economical solution of the problem before making public the information obtained.

The writer, being a member of the *Comité Technique,* invited to assist the new Panama Canal Company in directing its investigations and forming its conclusions, has had exceptional advantages for understanding the subject in its present aspects. The *Comité* is international in composition, and includes French, English, German, Russian, and American engineers—among them the chief engineers of the Manchester and Kiel maritime canals. It may be added that, in this respect, it reflects the view of the Company that the work should be broadly international in character, a benefit to the whole world, and not simply a French construction. Last spring the writer visited the Isthmus of Panama with other engineers, and personally examined the route in detail. He has had for many months free access to the elaborate records of surveys, borings, experimental excavations, river gaugings, and researches of every kind conducted by the Company, and is therefore qualified to present the subject in its true aspects, which may be found to differ widely from the popular impressions now existing in America.

When the idea of constructing a sea-level canal at Panama was definitely abandoned, there remained three important difficulties to consider: (1) The regulation of the water-supply, and control of the floods of the Chagres River; (2) the serious caving which had occurred at the Culebra; and (3) the ill effects of the climate upon the health of the employees. The present conclusions as to each will be given in turn.

(1) The studies of the regimen of the Chagres have been most elaborate; including water-levels, automatically recorded since 1883; frequent measurements of the discharge at crucial points; the collection and discussion of data respecting all the historic floods (five in number, of which one was carefully measured); rain records at points well distributed along the route of the Canal, aggregating fifteen years on the Atlantic Coast, thirteen years on the Pacific Coast, and thirty-two years in the interior; and, finally, a collation of all this material, and the elaboration of projects perfectly providing for controlling the floods, for the supply of the summit level with water during the dry season (January, February, March, and April), and for ample hydraulic power at the dams, transmitted by electricity, for operating the locks and lighting the Canal at night. It may safely be affirmed that the Chagres River is no longer an element of danger, but is rather a useful friend, whose assistance will be of great value to the Canal in its operation.

(2) The question of caving in the deep central cut has been studied in the most thorough manner; involving not only many borings and pits to determine the material to be encountered, but also a cunette excavated throughout the troublesome region along the axis of the Canal, having a projected width at bottom of 32¾ feet, with slopes of about 45 degrees, and a projected elevation above sea-level varying from 128 feet to 157½ feet. This work, together with a tunnel 689 feet long and 9¾ feet wide pierced, at an elevation of 134½ feet above sea-level, at the spot which had given the most trouble on the whole route, combined with the evidence afforded by the borings and pits at greater depth, leads to the conviction that, at Culebra, where the deepest cutting is required, the excavation has already passed through the strata subject to caving, and that the remainder traverses an indurated argillaceous schist changing to compact rock, where no fears of yielding to pressure need be entertained. At Emperador, where the cutting required for the Canal is much less, the indications are similar, except that the material at present reached is less resisting; but with proper precautions in the way of drainage, which were wholly neglected by the contractors of the old company, little or no difficulty from serious caving need be apprehended. This work of experimental excavation has been continued for more than three years; involving the removal of about 3,924,000 cubic yards. It was projected, partly to determine the proper inclination for the side slopes,

and partly to estimate the unit cost. The results are highly satisfactory; and the old bugbear of a sliding mountain divide has been proved to be imaginary.

(3) The health of the *personnel* formerly caused trouble; coolies and other races not well suited to hard labor under a tropical sun being employed. With negroes from the British Antilles, little difficulty is now experienced. This matter was carefully investigated during the inspection last spring; American engineers and employees on the Canal and Panama Railroad being questioned, the fine hospital near Panama—where the Company provides for its sick—being visited, and the views of the medical officers and of the Sisters of Charity, acting as nurses, being obtained. All agreed that the dangers resulting from the climate have been much exaggerated. The surgeon in charge of the hospital, Dr. Lacroisade, who has resided on the Isthmus since 1887, after presenting full statistics covering the sick-reports for the past year of a force of about 3,800 agents and laborers under employment, said:

"Among the diseases attributable to the climate the most numerous are simple marsh fevers, which have not occasioned a single death. Two diseases only belonging to the epidemic type have appeared—the beriberi, of which there is no longer any question" [it was imported with negro laborers brought from Africa as an experiment, and disappeared when they were sent back] "and yellow fever. The latter, after having been absent from the Isthmus for at least six years, was imported in 1897, and continued about six months, from March to August, when it again disappeared after very light ravages (only six deaths). Thus it cannot be considered that this pest is really epidemic on the Isthmus. From the other infectious epidemics, such as variola, typhoid fever, diphtheria, etc., the Isthmus appears to be almost entirely exempt. From the foregoing we may conclude that life on the Isthmus scarcely incurs more dangers than elsewhere, even for Europeans who, after the blacks of the British Antilles, appear to resist the climate best. Residence here would, then, offer nothing alarming, were it not for a constant feeling of fatigue and uneasiness due to a temperature always high, and an atmosphere saturated with moisture."

There appears, therefore, to be no danger of serious mortality in the construction of the Canal, if due care be taken to benefit by past experience in selecting the laborers.

The three old spectres baring the route being thus laid at rest, it remains to consider the present project for the Canal. This has been most carefully elaborated. No less than sixteen projects (not including the older proposals) have been worked out in detail, including estimates of cost and of the time needed for construction.

The entire length of the Canal is 46 miles, of which about 15 miles on the Atlantic side and 7½ miles on the Pacific side, or about one-half of the whole distance, will be at sea-level. Of this distance 18 miles, or about two-fifths of the entire route, is to-day essentially completed, so that at a moderate outlay for dredging it will be made at once serviceable. We have, therefore, only to consider the 23½ miles between Bohio, an the Atlantic side, and Miraflores, on that of the Pacific. Two excellent harbors, which will demand no outlay for protection, are available; and the Panama Railroad skirts the Canal throughout its entire route, to be availed of in construction. Ample quarters, in fair condition, for the increased force of laborers are already prepared at many sites. These advantages are immense where time is of so much importance.

There is another advantage, in my judgment scarcely less valuable. By careful technical studies, the Company has succeeded in provisionally adjusting the project so that a choice between the best three different summit-levels may be reserved, to be decided by actual experience in conducting the work upon a grand scale. These projects are designated as "level 96¾ feet," "level 69 feet," and "level 32¾ feet;" the figures indicating the elevation in feet of the bottom of the Canal at its highest level above mean tide, which is found at practically the same absolute level in both oceans, although the tidal range at Colon is only a few inches, while at Naos it may at times reach 20 feet. A comparison of the estimated cost of construction, properly so called, has established that, as between larger excavation on the one hand, and more locks and higher dams, etc., on the other, there will be nearly a balance of expenditure. The cost of either of the plans is estimated at about $100,000,000. It is not the same, however, when the element of time is considered. This will vary with the amount of excavation called for in the deep cutting at Culebra and Emperador, which will largely determine the duration of the work. The deeper this cut, the longer will be the time required to complete the Canal, and, consequently, the greater will be the outlay in general expenses of administration, interest on the funds to be raised, loss of revenue, etc. These are important elements of expense, sometimes neglected in estimates.

Basing the rate of probable excavation chiefly upon the experience acquired by the old Company in operating on a large scale, checked by that of the New Company in operating under many disadvantages upon a small scale, it has been computed that there will be required to complete the project of level 96¾ feet about eight years, and longer proportionally for the other projects. But it must not be forgotten that the old Company has been criticised, perhaps justly, for the mode adopted by its contractors in prosecuting the work; rapidity of execution not having been made an object to be specially sought. Also that great improvements have been introduced during the past ten years in machines and methods. It is, therefore, not unreasonable to expect that, with these improvements, and with better stipulations in the contracts, these estimates of time, at least for the higher levels, may be notably reduced, and excessive incidental expenses for interest, etc., be thus avoided. To be convinced of this, it is sufficient to consider the rapidity attained in excavating the ship-canals of Manchester and Kiel, and especially the drainage-channel at Chicago, where such great advances were made.

It is a great merit so to have adjusted the projects as to be able to pass readily from one to the other, if experience in the progress of the work should show this to be desirable. But how is this advantage to be secured? Simply by so adjusting the different levels as to permit the change to be made by omitting upper locks—thus calling for ten, or eight, or five locks, in the three projects, respectively.

All three projects require a dam at Bohio; transforming the Chagres River into a vast lake, of which the boundaries have been accurately determined. It will extend a distance of 13 miles to Obispo, where the Canal leaves the River, and will cover an area of about 21¼ sq. miles. Its lowest level is fixed at 52½ feet, its normal level at 55¾ feet, and its highest level at 65½ feet above mean tide. It thus provides a reservoir to retain one hundred and ninety-six million cubic yards of flood-discharge, which, with one hundred and thirty million more held back at Alhajuela in the Upper Chagres, will effectively control the torrential stream. Two locks will admit ships coming from the Atlantic into this lake. Thence, to attain the summit-level at elevation 96¾ feet, three locks will be required—all at Obispo; while for elevation 69 feet two will suffice, and for elevation 32¾ feet, one only, or perhaps none, will be necessary. The descent to the Pacific is made for the three projects, respectively, by two locks at Paraiso, two at Pedro Miguel, and one at Miraflores; or by one lock at Paraiso, two at Pedro Miguel, and one at Miraflores; or by two locks at Pedro Miguel, with a tidal lock at Miraflores.

All of these locks have a rock foundation; and none presents extraordinary difficulties. All are double; one chamber having a serviceable length of 738 feet and a width of 82 feet, and the other (for smaller vessels) the same length divided by a set of intermediate gates, and a width of 59 feet. The maximum lift is 29½ feet, except that provision for 32¾ feet is made at Bohio when, very rarely, and then only for a few hours, the lake may rise to maximum flood-level.

With respect to alignment of the Canal the following are the conditions adopted; The curves not to have a radius less than 8,200 feet, which experience has shown to be required for easy navigation; the depth to be 29½ feet, with provision at the locks for 31¼ feet should an increase ever become desirable; the cross-section never to fall below about three times the midship section of the vessels which will navigate the Canal; ample enlargements, at distances not exceeding 5½ miles, for ships to pass each other; bottom-widths of 164 feet in Lake Bohio and 98½ feet in the central part; retaining the existing width (72¼ feet) in the Atlantic level, to be enlarged to 98½ feet after the Canal is opened to navigation, 98½ feet in the Pacific level, and 164 feet in the channel extending through the bay from La Boca to Isle Naos where the Canal terminates.

Only two large dams are required,—the first at Bohio, creating a lake which, besides acting as a flood-regulator, will obviate the necessity of encountering strong currents where the route traverses the bed of the Chagres, a very important matter for ocean shipping; and the second at Alhajuela, in the Upper River, to assist in controlling the floods, to supply the summit-level in the dry season, and to furnish hydraulic power, transmitted by electricity for operating the Canal.

The dam at Bohio will be of earth revetted with stone, with a foundation bed of clay and abutting against rock banks. The extreme length of crest is 1,286 feet, the extreme height above the bed of the river is 75½ feet, and above the lowest point of the foundation 93½ feet. All details of construction, including the devices for controlling the River during the progress of the work, have been carefully elaborated, and will command the confidence of engineers. The sites for the two overflow weirs are remote from the dam; and an abundance of excellent material is found near at hand.

The dam at Alhajuela, about ten miles from the Canal, is to be of concrete masonry, founded on compact rock, and abutting against rock walls. The extreme length of crest is 936¾ feet; the extreme height above the bed of the river is 134½ feet, and above the lowest point of the foundation 164 feet. The cross-section and the practical details of construction are in accordance with all the requirements of modern engineering. Good rock and sand are abundant in the immediate vicinity.

To connect this reservoir with the summit-level, a feeder 10 miles long, starting at 190¼ feet above sea-level, is required. It traverses a rough country, and its construction will be relatively costly; but when compared with many of our irrigating canals west of the Mississippi it offers no serious difficulties.

The minor dams at Obispo, Paraiso, Pedro Miguel, and Miraflores will vary in height according to the project adopted; the first, second, and fourth will be of concrete masonry, and that at Pedro Miguel of earth. None of them presents difficulties worthy of note.

The regulating weirs will be of the "Stoney" design, which has given entire satisfaction on the Manchester Ship-Canal; and all of them will be detached from the dams.

Such is a brief summary of the present condition of the studies for the Panama Canal. It remains to compare the project with that at Nicaragua. The details of the latter are so fully presented in the report of the Government Commission of 1895 and accompanying documents, and are so well known in America, that a recapitulation in detail is not required here. The new commission, of which Admiral Walker is president, has as yet made no formal report; but the individual views of the three members were given in so much detail at the hearing before the Senate Select Committee in June last, that the modifications likely to be recommended may be inferred. The essential features of the project are the following: The whole length of the route is 176½ miles. Of this distance about 67¾ miles lie in the bed of a crooked river through which must pass the outflow of Lake Nicaragua, covering some three thousand square miles, and about 57¼ miles in the Lake itself, calling for from 10 to 14 miles of dredging in soft mud. The summit-level is fixed at 110 feet above mean tide; and both of the Government commissions recognize the extreme difficulty of regulating this level so as to avoid, on the one hand, flooding a valuable district on the Pacific side of the Lake, and, on the other hand, exposing rocks in the bed of the Upper

San Juan, where there are several bad rapids to be drowned or excavated before a ship-channel is possible.

The Nicaragua Canal Company advocates two principal dams, one at Ochoa on the San Juan, and the other at La Flor west of the Lake; but as the latter was regarded as impracticable by the Ludlow Commission, and apparently is not favored at the projected height by the Walker Commission, it will be left out of consideration. The Ochoa dam presents serious difficulties; and although the present commission has succeeded in finding a rock bottom at great depth (Admiral Walker estimates it approximately at 40 or 45 feet, and Prof. Haupt at 60 feet, below sea-level, *i. e.*, at 80 to 85 feet and 100 feet respectively below the deepest part of the bed of the river), no definite plan has yet been presented for modifying the loose rock and clay dam hertofore regarded as necessary. This construction is without precedent in canal engineering; and Admiral Walker says of it: "Of course a dam of lose rock would have to be enormous in size; it would be like moving a hill into the river."

But the alternative of digging from 80 to 100 feet to reach foundations in the bed of a river which cannot be temporarily diverted, and then of raising a masonry mass to a height of 150 to 170 feet above this newly discovered rock bed, is not an easy or a safe undertaking. Moreover, to hold the summit-level at 110 feet, enormous embankments are required in the San Francisco basin. They are sixty-seven in number and six miles in length; and some of them will rise from 60 to 85 feet above soft mud, which must be excavated to a depth of 30 feet to reach a clay foundation. The chief engineer of the Company regards these embankments as "the weakest feature of the whole route;" and they appear to have impressed the present commission, as they did that of which Gen. Ludlow was president, most unfavorably. Indeed, new surveys have been ordered to attempt to radically change the existing project, with a view to reducing the height of the dam at Ochoa and of the huge embankments, at the expense of making an equally deeper cut in the Eastern divide and of raising a second dam at Machuca Rapids, either retaining the site at Ochoa, or replacing the dam there by one at Tambour Grande below. Of this prospective change Admiral Walker says:

"We have had some parties out to find how far we would have to run embankments, and it is quite possible they may be as bad as the San Francisco embankments.... I think the chances are, by putting a dam at Machuca and a dam below at Ochoa, or Tambour Grande, and taking a low-level route, we may escape this heavy work and get into Greytown with considerable less expenditure of money, and with a canal that would not, perhaps, keep its superintendent awake at nights so much."

Evidently the plans of the Nicaragua Canal cannot be regarded as definitely determined. But it is not only in the construction ot the Canal proper that serious difficulties are to be encountered. When the writer traversed the transit route in 1856, the harbor at Greytown was open to the largest steamers, and presented no difficulty. To-day, owing to the travel of sand along the coast, under the influence of the wind and waves, the port no longer exists for seagoing vessels. The jetty constructed during 1890-93 by the Canal Company has proved a total failure, and the problem is now presented, not in the simple form of making a new port, but of re-opening an old one which nature has decided to close. American engineers have had experience in the difficulty and cost of such constructions at Fernandina, at the mouth of St. John's River, at Brazos, and at many other points; and before undertaking a canal it would seem to be prudent to re-open the port and determine the first cost and the probable annual outlay for maintenance. A canal, access to which would be subjected to oc-occasional interruptions from natural forces now known to be in action, would be a serious mistake; and it may be added that a study of the six charts accompanying the report of the Ludlow Commission, showing the condition of this port at five different dates between 1832 and 1895, is not reassuring.

As to the important element of the cost of the Canal, there appears to be considerable difference of opinion. The chief engineer of the Company estimated it, in 1895, at $69,893,660, and the Ludlow Commission, at the same date, at $133,472,893. Engineers will recognize the impossibility of exact figures in the present state of the investigations now in progress under the Walker Commission; and each of the members has carefully guarded himself from expressing a definite opinion. Admiral Walker, at his recent examination before the Senate committee said:

"We have made no figures. It is no use to figure on the thing until we have all our data. But I do not see why that canal cannot be built. I should think myself, speaking as anybody in the street might speak, that the Canal could be put through for 125 millions; and it would not surprise me if it came considerably below that."

Prof. Haupt, on the same occasion, stated that he thought the Canal could be built "inside of $90,000,000."

Gen. Hains said:

"I think a canal of the dimensions that have generally been referred to—30 feet deep, with locks 650 feet long, and all the cross-sections that have been referred to as necessary in rock and earth—could be constructed for a maximum sum of about $140,000,000, with a possible reduction of $25,000,000 or $30,000,000....But the trouble is that just now I am not prepared to give an opinion that would be worth anything."

Evidently, in view of previous experience in such works showing that the actual cost has usually very largely exceeded even carefully prepared estimates, it would be premature to form an opinion as to the outlay that will be required for the Nicaragua Canal; but a general idea of that demanded by the two routes may be formed from the following comparison:

Panama	*Nicaragua*
Two good harbors now existing.	Two harbors to be created; one of them (Greytown) presenting unusual natural difficulties.
A good railroad now existing along the entire route.	A long and difficult railroad to be constructed, which General Hains considers should extend along all the route, except the lake portion, *i. e.,* for a distance of 120 miles.
Actual construction, now well advanced (about two-fifths entire length actually completed) and remaining difficulties accurately known.	Practically nothing done in way of construction, and many of the essential elements undecided.
No constructions projected which are not justified by recognized engineering practice.	One or two dams projected wholly without precedent in canal work; and many embankments which must be permanent elements of danger.
Except the works at Bohio, no difficult excavations or constructions to be made where the annual rainfall exceeds 93 inches (only about 50 per cent. more than on our Gulf Coast).	The most difficult works lie in a region where the observations of the Canal Company indicate the annual rainfall to be nearly 22 feet (256 inches), or nearly three times as much as at the Panama sites.
Route lies wholly in Colombia, where all interests will be benefited by the Canal.	Route lies on the border of Nicaragua and Costa Rica, where local jealousy already exists, which may prejudice the interests of the Canal.
Distance to be lighted and supervised when the Canal is completed, 46 miles.	Distance to be lighted and supervised when the Canal is completed, 176 miles, or nearly four times as great as the Panama.
No active volcanoes within about 200 miles of the route of the Canal, and earthquakes therefore less probable.	Active volcanoes near route; one, Omotepe, on an island in Lake Nicaragua, and another, Orosé, only about 40 miles from the locks. An earthquake on April 29, 1898, at Léon, destroyed several buildings.

Cost carefully estimated on detailed plans at about one hundred million dollars.	Cost estimated by the Government Commission, on data recognized as wholly insufficient, at about one hundred and thirty-three million dollars.
Concessions from Colombia (upon which whole undertaking is based) ample, satisfactory, and unquestioned.	Concessions from Nicaragua and Costa Rica (upon which whole undertaking is based) either expired, or expire next year, and officially declared by Nicaragua to be forfeited and void.

But let us assume that both canals are constructed and open to navigation, and then compare the two routes, by considering which of them would be selected by vesels seeking to cross the Isthmus. This is a crucial test which will reveal their relative merits:

Panama	*Nicaragua*
Ports known to be good and easy of access.	Both ports artificial, to which access may be doubtful, especially on Atlantic side.
Length of route 46 miles, and time of transit 14 hours.	Length of route 176 miles, and time of transit not less than 44 hours.
Summit-level probably 103 feet and perhaps only 66 feet.	Summit-level 110 feet.
Locks double from the opening of the Canal, one chamber 738 by 82 feet, and the other 738 by 59 feet, with intermediate gates.	Locks single (subsequently to have another chamber added); dimensions 650 by 80 feet.
Curvature gentle. Smallest radius 8,200 feet. Of the 46 miles, 26¾ are straight, and 15 have radii equal to or exceeding 9,850 feet.	Curvature too sharp. Smallest radius in Canal proper 4,000 feet. For 68 miles the route traverses the San Juan river, where, to gain 47¼ miles as a bird flies, it is necessary to travel 67¾ miles—a loss of 43 per cent.
No troublesome winds or river currents to be encountered even in times of flood.	Heavy trade-winds and strong river currents.

It would seem from this analysis that there can be little difference of opinion as to which is the better route. But perhaps some enthusiastic advocate will say, "The Nicaragua Canal may be the more costly, may present more natural difficulties, may require more time for construction, and may be less easy of transit; but let us have an American canal, made with our own money, and wholly under our own control."

Such considerations are outside the province of an engineer. But, perhaps, it may be suggested that we have already interests and responsibilities on the Isthmus, where the Panama Railroad was built and is now controlled by an American company, under American protection; that the business control of any canal must vest in its stock and bond-holders in time of peace, while in fact in time of war—unless its neutrality be guaranteed by the great maritime Powers—the transit will be controlled by the belligerent having command of the sea.

May it not, then, be wiser for our Government to extend its powerful assistance to what Nature has determined as the best route, rather than to expend more time and more money for what, after all is said, must remain a distinctly inferior canal, unable to compete with its rival for the commerce of the world?

HENRY L. ABBOT.

Paris, August 9, 1898.

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GENERAL PLAN
OF THE
PANAMA CANAL
WITH DETAILS OF THE PROJECT BASED UPON A SUMMIT LEVEL OF 20.75 METRES
REENGRAVED FROM THE ORIGINAL
FOR
THE ENGINEERING MAGAZINE.
SCALE: 1/100,000
LEGEND
Line of the Canal.
Diversions completed.
Diversions uncompleted.
Line of the Panama Rail Road.
Deviation of the Panama Rail Road.
Feeding ditches.
Railroad from Gamboa to Alhajuela.
Line of Soundings of 11.32 metres
Buildings belonging to the Company.
Buildings belonging to individuals.
NOTE: Altitudes are expressed in Metres above the mean level of the two oceans.
Soundings are refered to the mean level of the two oceans.
Position of the Panama Cathedral 8° 57 16 Lat. N., 81° 51 04 Long. W of the meridian of Paris.
ATLANTIC OCEAN
PACIFIC OCEAN
BAY OF LAS MINAS
BAY OF MANZANILLO
COLON
I. MARGARITA
Monkey Hill
Light House
CHAGRES
Fort Lorenzo
San Jose
Naranjitos
Playa de Flor
San Andres
Village of Rio Pinia
GATUN
Lion Hill
Tiger Hill
Ahorca Lagarto
BOHIO SOLDADO
Frijoles
TAVERNILLA
SAN PABLO
Mamei
Juan Grande
GORGONA
MATACHIN
OBISPO
EMPERADOR
CULEBRA
PARAISO
Pedro Miguel
Miraflores
Rio Grande
COROZAL
PANAMA
La Savane
BAY OF PANAMA
I. PERICO
I. FLAMENCO
I. CULEBRA
I. NAOS
I. CHANGARNI
I. TORTOLA
Venado
Hacienda de Cabra
Ruins of Old Panama
ALHAJUELA
Gatun
Cruces
Palo Grande
Las Cascadas
Cocoli
Monte Lirio
La Soledad
Agua Clara
Rancho del Tigre
Rancho Camcho
Lagartera
Palo Matias
Calle Bruja
Swamp of Agua Clara
Shortening of the Principal Sailing Distances.
Distances are given in Nautical Miles of 6,080 ft.
BORMAY & CO., ENGR'S N.Y.