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THE NICARAGUA CANAL

BY

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THE NICARAGUA CANAL.

It is assumed that the reader is sufficiently acquainted with the early history of Isthmian transit and the various tentative explorations and surveys conducted under the auspices of the United States Government, and by private individuals, from Tehuantepec to the southern limits of the Isthmus of Darien, with the view of ascertaining the most practicable route for the safe and economical construction of the canal, and that, after several years of most careful and thorough investigation, regardless of expense and labor, the field of inquiry was narrowed down to Panama and Nicaragua. In 1876, a high commission appointed by the government, gave its final decision in favor of the latter route as possessing the greatest facilities for the economical and safe construction of a waterway between the Atlantic and the Pacific. This decision was later on disregarded by the Paris International Canal Congress; for in May, 1879, it voted in favor of a sea-level canal at Panama as the most advantageous and desirable route, for a profitable enterprise and a safe waterway. The sad history of that unfortunate undertaking is ample justification of the action of the commission and an unquestionable proof of the soundness of their conclusions. And yet it may be proper to say that the plans now under consideration are far more complete than those considered and indorsed by the commission.

THE SURVEYS.

Government investigation and American enterprise did not rest with that decision. There was a restless desire to improve, if possible, on what was already known to be good; and, regardless of the attempt (which it was believed would prove fruitless) to overcome insurmountable difficulties at Panama, government expeditions and private surveying parties succeeded each other at Nicaragua from 1880 to 1890, and the whole ground was gone over again. Every river, watercourse, valley, swamp, or hill likely to affect the construction of the work was carefully examined. Thousands of miles of transit and level lines were run in some sections of the route before a mile of canal location was finally decided upon; and this data, together with numerous borings, penetrating to the bottom of the canal, and at the sites of dams, locks, and embankments, comprise a vast store of exact knowledge, from which a final location has resulted, as perfect in its details, it is believed, as the natural conditions will permit. The greatest obstacles met with at other localities are high elevations in the Cordillera separating the two oceans, requiring tunneling, or a high summit level with a large number of locks for which an adequate water supply was not obtainable, or torrential streams are encountered whose control within economical limits defies the skill of the engineer.

Nicaragua is free from all these obstacles.

NICARAGUA LAKE AND RIVER.

The great lake, a veritable inland sea, 110 miles in length by an average of 40 in width, is the recipient of a watershed of 8,000 square miles, of which its water area represents nearly one-half. Its outlet, the river San Juan, is a noble stream. Its source is at the south-eastern extremity of the lake, and flows through a broad valley, almost due east, for a distance of 119 miles, to its mouth in the Carribean Sea, south of Greytown. Its minimum flow is 12,000 cubic feet per second: the width varies from 800 feet to 2,000 feet, and the average fall is 11 inches per mile. Its main source of supply is the lake, which, by reason of its large area, restricted watershed, and ample outlet, is not subject to sudden or large fluctuation in level. Both the lake and river are, therefore, free from floods; and it is this important, invaluable feature which distinguishes this route from all others, and which enables us to make use of the lake and a large portion of the river as parts of the canal. The lake is separated from the Pacific by a narrow strip of land, a true isthmus, but 12 miles wide at its narrowest point. It is at this point, also, that is found the lowest depression in the Cordillera all the way from the Arctic region to Cape Horn, and the summit, or crest, of the ridge rises but 42 feet above the lake, or 152 feet above the seas. Through this gap will be cut that section of the canal connecting the lake with the Pacific, and terminating on the coast at Brito, a small roadstead where a harbor is to be constructed. From the lake eastward the river San Juan supplies the transit route to a point below its confluence with the San Carlos tributary, where the canal leaves the channel of the stream, by a series of short sections in excavation, connecting a chain of artificial basins, and stretches in a well-maintained straight line to Greytown, the Atlantic terminus of the waterway. This general outline and an inspection of the map and profile will materially assist in arriving at a clear understanding of the route and engineering works proposed, which will now be described in detail.

THE CANAL ROUTE.

The lake, which is the controlling feature of the whole problem, is, necessarily, the summit level of the canal. The average yearly fluctuation of level due to wet and dry seasons is about 5 feet, its highest water-mark being 110 feet above the sea; and that is the elevation assumed for the highest summit level of the canal. A direct sailing line between the outlet at Fort San Carlos, on the east coast, and the mouth of the river Lajas on the west, a distance of 56.5 miles, comprises the lake navigation proper. On that line the 30 feet contour (below the assumed level of 110 feet) is met with, about 14 miles from the outlet and 1,200 feet from the west shore. Between those points the depth gradually increases to 150 feet or more, the free navigable portions comprising the greater part of the lake area. Dredging in mud to an average depth of 9 feet will be required in the 14 miles on the east, and rock-blasting and dredging in the 1,200 feet near the west shore. Two piers are proposed on the west coast to protect the canal entrance.

While the isthmus separating the lake from the Pacific is, at its narrowest point, not more than 12 miles in width, the most economical route connecting the lake shore with Brito has a length of 17.04 miles. It starts from the mouth of the Lajas, a small stream draining a limited watershed to the south of the line, and trends westerly through a broad valley slightly rising toward the "Divide," which it reaches at a distance of 4.70 miles from the lake. Descending thence on the Pacific slope, at the rate of about 9 feet per mile, at a further distance of 1 3-4 miles it falls into the narrow, tortuous valley of the Grande, a dry creek during the dry season, but a stream of considerable flow in the rainy portion of the year. Its maximum volume has been estimated as high as 10,000 cubic feet per second; but this is attained only in times of extraordinary precipitation. In this narrow valley, confined by spurs of considerable elevation projecting from the highlands on both sides, there is not room for the canal and for an independent channel for the stream. A very favorable location has been made for the former, and it will be shown later on what disposition is proposed to be made of the stream. In 1 1-2 miles the Grande makes a detour to the westward; and the canal, free from the confining hills on the north, cuts across a broad valley to fall again into the stream at a distance of 9 miles from the lake. At this point the surface of the ground is 30 feet below the assumed level of the lake. The valley continues its uniform descent of about 8 feet to the mile, and gradually expands until, at the junction of the Tola tributary, it attains the maximum width of 12,500 feet. At mile-post 14, near a place called La Flor, the Grande passes through a narrow gap, flanked by high hills, into the more extensive plain of Brito, bordering on the Pacific. It was the original plan to cut a canal through this valley of Tola, and four locks were contemplated, with the aggregate lift of 110 feet; but another scheme has since been adopted by which the valley in question is flooded and converted into an extensive navigable basin. This will be accomplished by closing the gap at La Flor by a dam 1,800 feet long and 70 feet high, so forming a basin whose surface level will be the same as that of the lake, and, in fact, forming a part of it. The basin thus created will be 5.60 miles long on the sailing line, with a depth of water varying from 30 feet to 70 feet, and will have a superficial area of 4,000 acres. The advantage gained by this plan consists not so much in saving canal excavation for a distance of over 5 1-2 miles (which is partly offset by the cost of the dam), as in the increased facilities offered to traffic by the large, deep, and safe inner harbor, within 3 miles from the Pacific port, where ships can lie at anchor, or pass each other with safety and freedom when moving in opposite directions. A better control and disposal of the surface drainage is provided by this treatment. Two locks will be placed at the western end of the dam, by whose combined lift the level of the water will be lowered 85 feet; namely, from 110 feet above sea level to 25 feet. From these locks the canal route traverses the valley of Brito, a distance of 1.58 miles, to lock No. 6, where the last drop of 25 feet is made to sea level. But, as a tide of 8 feet must be provided for, the lock will have a variable lift of from 21 to 29 feet. From this last lock to the harbor will be about 1-2 mile of canal, but the prism has been so enlarged as to make that portion of the waterway an extension of the harbor itself.

BRITO.

The only well-founded criticism to the Nicaragua route for an interoceanic canal is the lack of good harbors; but an examination of the existing physical conditions will show that, while the construction of ample and safe ports will necessarily involve important and expensive works, yet the cost is not out of proportion to the magnitude and importance of the undertaking, and the engineering problems do not present more serious difficulties than those readily mastered elsewhere for objects less important.

Brito, barely a roadstead, is an indentation of the coast, formed by a projecting spur from the coast range. About 1 1-4 miles to the southward another headland juts into the sea. Between, lies a cove now filled to about sea level with river silt and sand; but this opening, it is believed, was once an arm of the sea. The Grande traverses this low land through a narrow channel; and in it the tide ebbs and flows, with a depth, at the entrance, of about 10 feet at high water. The designs for the creation of this harbor contemplate the construction of two breakwaters, one about 1,000 feet long, projecting from the rocky promontory on the west, and the other 850 feet long, and nearly normal to the beach on the east side. (See plan of harbor.) The entrance will be between the jetties, and a considerable deep water area will be confined; but the main portion of the harbor will be excavated in the alluvial valley of the Grande, the whole forming a broad basin penetrating 3,000 feet from the present shore line and about 4,000 feet from the entrance. Beyond this basin an enlarged section of the canal, about 3,000 feet long, extends to the nearest lock, and forms a substantial portion of the harbor itself.

DRAINAGE.

The proposed route of the canal, from the lake nearly to the summit of the Divide Cut, pursues a right line. The Lajas has its source in the hills to the southward, and in its course to the lake intersects the canal line at a distance of 1.25 miles from its mouth. At this point the stream will be diverted through an artificial channel, carried along the south side of the canal and discharged into the lake. A small tributary empties into the Lajas near the point of proposed division of the latter. This brook, called the Guiscoyol, will drain the country to the south as far as the highest point of the line; and the canal follows the general course of this brook. It will be observed that the Rio del Medio, to the north of the canal, drains the country on that side from the vicinity of the Tola basin to the lake, leaving but a small watershed to be drained into the canal or, if preferred, by a small ditch which may be diverted to the lake. West of the Divide the canal, including the Tola basin, lies within the watershed of the Grande. With the canal wholly in excavation, no doubt could be entertained as to the necessity of diverting that stream; and careful surveys have been made with that object in view. It was found that to make a diversion channel on the south bank of the Grande would be a work involving some difficulties and heavy expense. A safer, less expensive, and far more satisfactory plan was found to be the diversion of the stream into the Juan Davila, a tributary of the Lajas, and through the latter into the lake; and a careful location has been made to that end. (See plan of western division.) The plan requires the construction of a dam near "El Carmen," and the opening of a canal of diversion from above the dam, through the valley of Jobite and the watercourse Cumalcagua to the Davila, beyond which no other work will be needed. With the adoption of the basin plan, however, the additional expense demanded by this work seems to be of doubtful expediency. With a large reservoir acting as equalizer of floods, possessing ample facility for discharging the surplus waters over a weir in connection with the dam, through the lock culverts capable of discharging 5,000 cubic feet per second, and through the canal itself eastward into the lake, it does not seem that any injurious results need be feared by receiving the waters of the upper Grande into the basin, especially as the extraordinary floods, which seldom occur, are of but brief duration; and, except at such times, the flow of the stream is insignificant, while for nine months in the year it is *nil.* The problem, in any case, admits of a practical and satisfactory solution; and perfect immunity from all danger can be secured by the expenditure of, say, $1,500,000. From the Tola basin to the harbor the canal traverses a flat valley, with no watercourse to provide for.

THE RIVER SAN JUAN.

From the lake eastward this river will be made navigable for a distance of 64.5 miles by the erection of a dam at Ochoa, and by dredging for the first 28 miles below the lake. Rock-blasting will also be needed for a short distance at Toro rapids. The dam at Ochoa will there raise the water 56 feet. It will be 1,250 feet on the crest and 1,900 feet between abutments, with a maximum height of 70 feet. The river in its natural condition from the lake to the Atlantic, a distance of 119 miles by its course, has an average fall of 11 inches per mile; but this slope is not uniform. There are rapids at Toro, Castillo, and Machuca, with an aggregate fall of about 20 feet in a total distance,—for the three, of not more than 2 1-2 miles, the fall at Castillo being 4 1-2 feet in a distance of 1,000 feet. On the other hand, between the lake and Toro, and for 15 miles below Machuca, the fall is not more than 1 inch per mile. Two rapids, where the first rock ledge across the river is met with, is the natural weir which maintains the present lake level, the crest being 9 feet above the proposed bottom of the navigable channel. At Castillo, where the ledge is 7 feet lower, 3 feet of rock excavation for a short distance will be needed; and over the present Machuca rapids, 12 miles below, the depth of water as raised by the dam will be not less than 34 feet. Between the lake and Toro dredging to an average depth of 4 1-2 feet will be required throughout an aggregate distance of 24 miles, the material to be removed being gravel, clay, and loose stones. Below Toro no excavation will be needed in the bed of the river, except at the ledge at Castillo. Between the rapids the depth of water attained will vary from 30 to 50 feet, and from Machuca to the dam from 60 to 130 feet. The width of the navigable channel, where no excavation is required, will average 1,000 feet, and, in excavation, 125 feet at the bottom. The surface width will at no point be less than 1,200 feet, expanding in places to 2,500 between the banks, and in the flooded adjacent valleys to 1 mile or more. A fall of 3-4 of an inch to the mile has been allowed from the lake to the dam as the necessary slope to discharge the surplus waters. Consequently, the level of the river at the dam is estimated at 106 feet above sea level, or 4 feet below the lake. For the purpose of navigation, however, that portion of the river may be regarded as an extension of the lake, in which the maximum current will probably never exceed 1-2 mile an hour.

THE SAN CARLOS.

A short distance above the dam the river San Carlos debouches into the San Juan from the south. This stream drains a large area in Costa Rica, and possesses in marked degree the general characteristics of a tropical torrential river; namely, extreme fluctuations in volume from a nearly dry bed, with barely enough water to float a canoe, to a discharge of, possibly, 3,000 cubic feet per second. Its upper channel and tributaries, confined by high banks and flowing from mountain slopes, gradually broaden and flatten as they approach the lowlands near the San Juan, and the flanking hills recede from the banks, so that for a few miles above the confluence, the San Carlos flows through a wide valley, elevated but a few feet above the bed of the stream. This valley will be flooded to the same level as the San Juan (106 feet), and thus converted into a large basin, or artificial lake, constituting a part of the summit level of the canal, navigable for some twenty miles toward the Costa Rica capital. The San Carlos will discharge into this basin, or artificial lake, at a locality some 20 miles distant from the nearest point of the canal navigation. The San Carlos is the only sand-bearing stream emptying into the waters of the canal. Discharging its waters into a basin of still water, it will deposit all the heavier sand and silt now brought from the highlands, by the rapid current, 20 miles from the canal line. The lighter material held in suspension will be carried along with the slowly moving current, which will always seek the nearest outlet, and be discharged over the vast weirs to be built in the confining ridge several miles south of the San Juan, and will never reach the channel of the latter stream. The lower part of the valley of the San Carlos will be flooded to a width of from 1 to 2 miles, and to a depth of 60 feet. It will require a long term of years to fill this basin so as to encroach on the canal navigation. When that time does come, the San Carlos waters can, if desired, be diverted entirely by throwing an embankment across the valley and discharging the waters over the weirs previously built, and through existing watercourses in the San Juan far below Ochoa.

The confining ridge to the east of the valley extends from the south abutment of the proposed dam in a southerly direction for a distance of 10 miles to the foot of the high mountains of the interior of Costa Rica. There are, however, several depressions in which the ground falls below the contour 114, adopted as top of the confining barrier. These gaps will be closed by embankments, seven of which will be built wholly above the normal water level in the basin, eleven will have an average height of 21 feet, and two of 50 feet, with an aggregate base length of 130 feet, the total length of embankments on crest being 5,893 feet.

THE SAN FRANCISCO.

The canal, as it leaves the river channel a short distance above the Ochoa dam, is located in the lower valley of Machado Creek. Continuing easterly, it will cross the ridge dividing the valley of the Machado from a swampy region known as Florida Lagoon. It crosses the latter, and then, by a short cut, enters the valley of the San Francisco; and, skirting some foot-hills to the south, it enters the valley of the Chanchos, follows this stream to its junction with the Limpio, and thence *via* the valley of the latter to the foot of the dividing ridge. An examination of the plan will be necessary to a clear idea of the topographical conditions existing in this region. It has required much time, labor, and perseverance to develop this topography, and the most careful study to make profitable use of the information thus acquired.

It will be observed that the canal traverses four adjacent valleys. The Florida Lagoon drains into the basin of the San Juan by a small watercourse, the Danta; the San Francisco Valley by the stream of the same name; and the Limpio and Chanchos by the brook Chanchos, tributary of the San Francisco, the latter, as well as the Danta and Machado, being tributaries of the San Juan. All these valleys are to be converted into large, deep, navigable basins by extending through them the summit level from Ochoa. Their outlets must therefore be closed by embankments; and the foot-hills, wherever their crests fall below the contour 114, must be raised to that level. The main embankments will have to sustain a water pressure of about 60 feet, the level of the valleys being about 46 feet above the sea. Six embankments will have an aggregate base length of 3,440 feet, and on the crest, of 13,685 feet. The embankments to close gaps in the chain vary considerably in height. Many of them are wholly above the ordinary water level in the basin,—*i.e.*, from 1 to 8 feet high,—while other gaps require embankments of much greater height. They are 61 in number, with a total length on the crest of 17,835 feet. (See profile showing development of the San Francisco embankment line.)

Several important advantages are gained by this treatment. The total length of basin created is 11,267 miles, of which 8,697 miles will have a water depth varying from 30 to 60 feet. In other words, of the 12.50 miles from the bank of the river San Juan to the deep cut to the eastward of this section, but 1,233 miles will be wholly and 2,570 miles partly in excavation. The economy, however, is not confined to the saving in excavation, against which must, of course, be charged the cost of the embankments, but is principally in the enormous saving in the deep rock excavation following, and in the valley of the Deseado beyond, by carrying the summit level through into the valley of the stream. The increased cost to result from a plan contemplating a much lower level would have been so great as to seriously handicap the undertaking financially. The gain in facilities of navigating and maintaining the canal is also important. Through wide and deep basins vessels can move at full speed, lie at anchor, or pass each other at all points, while in the restricted channel the position and speed of ships must conform to rigid regulations. The problem of drainage also admits of a more favorable solution. A low, level route from Ochoa to the Atlantic would be longer by about 12 miles, and wholly in excavation. In order to avoid the high ridges and projecting spurs, it must keep close to the banks of, and be but a little elevated above, the San Juan. The canal would therefore be in constant danger of destruction,— on the south by the river floods, and on the north by the accumulated drainage of an extensive watershed, presenting at all points complicated engineering problems of most difficult solution. By the high-level plan, the largest portion of that watershed is eliminated; and, of the balance yet affecting the canal, a large area is converted into extensive reservoirs, from which the surplus waters can, without difficulty, be discharged over waste weirs on the confining ridges into the low valley on the south, and through the numerous watercourses traversing the same into the San Juan.

THE EASTERN DIVIDE CUT.

Proceeding eastward, the route, on leaving the basin, cuts across a narrow neck of the intervening ridge, which is a spur of the main Cordillera bounding the San Juan watershed to the north. The topographical conditions here are remarkable and extremely favorable.

This ridge, as a broad mass of hills, extends on the south to the banks of the river San Juan, often rising to elevations of 1,500 feet; and on the north it merges into the main Cordillera, but at the point selected the spur is nearly divided on the west by the valley of the Chanchos and Limpio, and on the east by that of the Deseado. It will be observed that the axes of these two valleys lie on a generally direct line between Ochoa and Greytown, and that their floors are at about the same level.

The ridge is thus greatly contracted; and here is also the lowest gap in the range for many miles on either flank, its highest point being about 299 feet above sea level. The cut through this pass will be 2.91 miles long, with an average depth to the canal bottom of 141 feet; but at one point projecting a spur must be severed that requires a maximum depth of cut of 328 feet. The summit, or lake, level is carried through this excavation and 3.08 miles beyond into the valley of the Deseado.

THE DESEADO.

At this point the valley is spanned by a dam 70 feet high and 1,050 feet long, which, together with several small embankments in the gaps of the ridge, aggregating in length 5,800 feet and having an average height of 20 feet, encloses a basin over 3 miles long, in which a depth of from 30 to 70 feet is obtained without excavation for a distance of 2.60 miles. The summit level, therefore, stretches from the upper lock on the Pacific slope to this point, a total distance of 154 miles, or from within 2 1-2 miles of the Pacific to within 12 3-4 miles of the Atlantic.

The upper lock in the eastern slope is located close to this dam. It will drop the level 45 feet into another basin formed by a second dam, 43 feet high and 820 feet long, and five embankments with total lengths of 1,763 feet by about 20 feet high, to close depressions in the confining ridges. The length of this basin is 1.95 miles, the water level 61 feet above datum, and the depth 30 feet or over. By lock No. 2, at the lower end of the second basin, the water level is again lowered 30 feet into a third basin extending for a distance of 1.25 miles to lock No. 1. By connecting this last lock with the flanking hills by ten small embankments, the lower section of the valley is partially flooded and the excavation materially reduced thereby. Lock No. 1 drops the canal 31 feet to sea level. From this point to the harbor of Greytown (San Juan del Norte), a distance of 9.30 miles, the canal traverses an alluvial sandy and swampy plain, but little elevated above the sea, with no features deserving special mention.

THE PORT OF GREYTOWN.

The harbor of Greytown some thirty years ago was yet a good and safe port, with an inner bay of about 500 acres area, with from twenty to thirty feet of water enclosed from the sea by a narrow sand spit extending from the main shore on the east to within a few hundred feet of the main land to the west. The westerly advance of the spit by the shifting sand, under the influence of the north-east winds and waves, had been gradually contracting the entrance for a long period, so that at the time referred to, the channel was already quite narrow, with but 25 feet depth of water opposite the extremity of the spit, or "hook." Nothing being done to check its progress, the spit continued to encroach upon the inlet; and about 1860 the harbor became a lagoon, separated by a narrow sand bank from the sea. After long-continued observations and investigations and due consideration of experience gained elsewhere in analogous conditions, the following plan has been adopted for the restoration of the harbor: —

To build a jetty, perpendicularly to the shore line, projecting seawards about 3,000 feet to the 6 fathom curve, and dredging under the lee of this breakwater an entrance into the lagoon, which will also be deepened over an area of 200 acres to the uniform depth of 30 feet. The shifting sands, arrested by the jetty, will gather in the east angle formed by it and the coast, will cause a gradual advance seawards of the new shore line, and in the course of time shoaling at the end of the pier, with tendency to move around and form a new bank across the entrance. This can be avoided by short extensions of the jetty from time to time as may be required, until the new coast line on the east becomes, in its general direction, perpendicular to the prevailing north-east winds. No farther change on the coast need then be apprehended, and the permanent restoration of the harbor will be accomplished.

The breakwater is to be built of "pierre perdue," the stone to be brought by rail from the Divide Cut. But in order to start the work, pending the construction of the railroad as far as the Divide and the beginning of active operations there, it was decided to build the shore end of the pier of a creosoted timber frame filled with fascines and rock, or concrete blocks, leaving it to the shifting sands to fill the voids and form a compact structure. It was expected by this means to afford enough protection to permit the opening of a sufficient entrance channel, which was imperatively demanded for the safe and economical landing of the stores and plant necessary for commencing the main work on the canal. The wisdom of this plan is shown by the results obtained, surpassing the most sanguine expectations. By the time the pier had been extended 600 feet into the sea, and without any assistance by dredging, a channel with 8 feet of water was obtained; and a short time later vessels drawing 12 to 15 feet of water had no difficulty in entering the inner bay. The first 1,000 feet of the jetty have already been thus built; and it is expected that the wood-work will soon be protected by stone from the excavation, and the work thus made permanent. It is proposed to dredge the entrance channel to a depth of 30 feet, with a bottom width of 500 feet, increasing gradually to the 34-feet curve opposite the head of the breakwater.

RAINFALL.

The total annual rainfall in Greytown in 1890 was 296.94 inches, in 1891 214.27 inches, and in 1892 291.15 inches. The maximum rainfall recorded is about 6 inches in 24 hours. The amount of precipitation decreases rapidly from the Atlantic coast to Lake Nicaragua. Records kept in 1890 at Greytown and at the foot of the Eastern Divide, about 10 miles inland, show a decrease of 34 per cent.

Records kept at Rivas, west of Lake Nicaragua and five miles from the canal line, from 1880 to 1889, show a maximum annual rainfall of 87.21 inches in 1886 and a minimum of 34.54 inches in 1885. Practically, no rain falls from November to May on the west side, while on the Atlantic slope more or less rain falls every month; but from February to May it is comparatively dry. Ample provision has been made for the disposal of the surplus water in designing the works.

DRAINAGE.

The problem of disposing of the surplus waters in that portion of the route from the basin of the San Juan to the lower Deseado will now be considered. The flow of the San Juan at Ochoa at high flood in both the San Carlos and San Juan has been found by careful gauging to be 42,000 cubic feet per second. The river is known to have risen somewhat higher; but, as no gauging was made at the time, the above figures will be increased by 50 per cent., making the possible maximum flow 63,000 cubic feet per second, of which not less than two-thirds would probably come from the San Carlos, the upper San Juan not being subject to great alternatives of flow. The combined basins of the San Francisco region have a watershed of about 65,000 square miles; and, assuming a maximum rainfall of 12 inches in 24 hours, about twice the greatest rainfall, there will result a possible discharge of 21,000 cubic feet per second from the San Francisco basins. The watershed of the upper Deseado basin is about 12 square miles, which on the above basis will yield a discharge of, say, 4,000 cubic feet per second, making a total of 88,000 cubic feet per second, for the discharge of which provision must be made. No deduction will be made on account of consumption in lockage, which may reach 1,500 cubic feet per second, nor for leakage, which may take up a much larger amount. Considerable allowance should, however, be made for the new conditions established by the introduction of large reservoirs, which will hold the waters back and regulate their gradual discharge in lieu of rapidly inclined streams fed by precipitous watersheds, which collect and discharge the rain water almost as fast as it is precipitated. Yet all these considerations will be for the present kept in reserve as a large margin of safety.

Provisions will first be made for the discharge of 63,000 cubic feet per second from the basin of the San Juan. In doing so, care will be taken to prevent any large discharge at any one point, which is likely to cause serious accidents by undermining and scouring or undue sudden changes in the level of the water. A large overflow in the vicinity of a dam will be avoided; and in the San Juan basin the current should be directed for its outlet towards the southern end of the San Carlos basin, or, at any rate, the water of that river must be excluded from the navigable channel of the canal as much as possible. This can be done by placing three or four weirs, with an aggregate length of crest of 1,200 feet, as far south on the eastern confining ridge as practicable. Their discharge will be led off into the swamps and lagoons immediately to the east of the ridge, and thence by Curena Creek into the San Juan about 5 miles below Ochoa dam. In this manner the sediment-laden waters of the San Carlos will be discharged directly, before reaching the San Juan, and the heavy deposits of silt so excluded from the valley. The crest of the weirs will be placed 18 inches below the crest of the Ochoa dam; and in ordinary conditions the surplus waters will escape through these weirs, which will be the lowest outlets.

It is proposed to place the crests of the Ochoa dam (1,250 feet long) at 105 feet above datum, or one foot below the water level of the canal at that point. The discharge under varying conditions of level will then be approximately as follows:—

	Cubic feet per second.
At normal level, 106′,	2,900
At 110 feet level,	32,000
At 111 feet level,	42,500

The crests of the weirs on the ridge will be placed at 103.5 above datum, and their discharge for the total length of 1,200 feet may be estimated as follows:—

	Cubic feet per second.
At normal level,	11,300
At 110 feet level,	47,700
At 111 feet level,	65,300

The combined discharge over the dam and weirs at normal, 110 and 111 feet, levels will therefore be, respectively, 14,200, 79,900, and 107,800 cubic feet per second; that is, to say, the maximum floods will be discharged before the level of the basin rises 4 feet above normal. In fact, it is unlikely that the level will ever rise nearly to that height as assumed, as a rise in the San Carlos basin will have the effect of checking the flow of the San Juan, and possibly reverse the current temporarily towards the lake. For the drainage of the San Francisco basin, three weirs, with a total length of overflow of 600 feet, will be built on the bordering ridge, so placed as to carry off the surplus water without producing injurious currents in the basins.

By placing the crests at the uniform level of 104 feet the discharge will be: —

	Cubic feet per second.
At normal level,	4,100
At 110 feet level,	21,200
At 111 feet level,	26,700

In the upper Deseado basin 300 feet of overflow at 104 feet level will give the following discharges in round numbers: —

	Cubic feet per second.
At normal level,	2,000
At 110 feet level,	10,600
At 111 feet level,	13,300

These provisions are more than ample to meet the maximum requirements in each of the basins, without causing undue current in the short cuts connecting them.

The possible accumulated discharge from the summit level at a given time may therefore be put down as follows:—

	Cubic feet per second.
At normal level, ...	20,300
At 110 feet level, ...	111,700
At 111 feet level, ...	147,800

It may be confidently asserted that the second figures will never be reached, and that the crest of the Ochoa dam may be raised above the water level in the San Juan, and yet the highest floods will not reach the 110 feet contour, the weirs being ample to so limit it.

Other provisions, however, have been made with the view to aid in construction, to facilitate repairs, and, as additional precautions, to meet possible contingencies, specially in the series of embankments in the San Francisco ridge, which, it is frankly admitted, is the weakest feature in the whole route. These safeguards consist of a guard-gate to be placed in the cut connecting the valley of the Machado with Florida Lagoon, by which the flow of water from the San Juan towards the San Francisco basin can be shut off, and two anti-friction gate sluices, one in the San Francisco ridge and the other in that of the upper Deseado, by which the water in these basins can be drained off to 30 feet below normal level, thus relieving the embankments of that pressure during construction, and enabling repairs in the cuts and embankments afterwards.

These sluices have openings of 25 feet by 20 feet, with the lower sill 30 feet below the normal level. Their capacity of discharge will vary with the head, being 12,500 cubic feet per second for each when the water stands at the 106 contour.

By these means 25,000 cubic feet per second additional can be drawn from the summit level, regardless of the lock culverts, through which 4,500 cubic feet per second more can be spilled.

The middle Deseado basin will be drained by weirs, with 400 feet length of crest, which will be two feet below ordinary level, and capable of discharging from 2,700 cubic feet per second to 14,100 cubic feet per second at 61 and 65 feet levels respectively.

In the lower basin 500 feet lengths of weir are provided for, the estimated discharge being from 3,400 cubic feet per second to 17,000 cubic feet per second, respectively, at normal and 35 feet level. Beyond the lower basin the surplus waters are diverted by a short cut into the San Juanillo, and through the latter into the San Juan to the sea.

From lock No. 1 to the harbor no special provision need be made to drain the adjacent country. The canal trave ses a swamp with numerous natural drains; and, being flanked on both sides by high embankments made by the earth spoil, it needs no additional protection.

OTHER CANALS.

It will be interesting to compare the sections first proposed for the Nicaragua Canal with those of other ship canals existing and proposed: —

Canals.	Depth in Feet.	Surface Width.	Bottom Width.	Area of Prism.	Length in Miles.	
Suez, original dimensions, earth,	26.20	328.0	72.2	4,170	100.0	Existing.
Suez, enlarged dimensions, earth,	27.90	328.0	112.9	5,412		Enlarging.
Nicaragua, rock section, . . .	30.00	184.0	80.0	2,400	7.8	
Nicaragua, earth section, . . .	30.00	184.0	80.0	3,960	9.7	Proposed.
Nicaragua, earth section, . . .	28.00	288.0	120.0	5,212	9.3	
Manchester, earth section, . .	26.00	172.0	120.0	3,796	35.0	Nearly completed.
Manchester, rock section, . . .	26.00	130.0	120.0	3,250		
Amsterdam, earth section, . .	23.00	186.0	88.5	3,156	15.5	Existing.
Corinth, rock section, ...	28.00	77.4	72.2	1,945	4.0	Nearly completed.
Panama, earth section, ...	27.80	160.0	72.2	3,227	47.0	Proposed.
Panama, rock section, ...	29.50	91.8	78.7	2,513		
North Sea and Baltic, earth, . .	28.00	197.0	85.0	3,930	60.0	Constructing.
Bruges, ...	26.26	223.0	65.6	3,789	6.5	Proposed.

N.B.—The dimensions given are taken at mean low water.

The Suez Canal cost $100,000,000, and in 1883 passed 3,307 vessels, with net tonnage of 5,775,861 tons before its enlargement was undertaken. This was accomplished, notwithstanding the fact that the channel was so narrow that sidings had to be constructed into which one vessel had to be placed while another was passing. In the Nicaragua Canal the narrow rock sections are divided into two and the east sections into many short lengths, separated by broad and deep basins, through which the largest vessels can steam and meet others without slacking speed.

It was originally planned that some sections of the canal in earth would be 80 feet in bottom width, with side slopes of 1 1-2 to 1 and in the rock cuts with vertical sides. This would accommodate the traffic for several years; and then the areas in cross section could be increased out of the earnings, as at Suez, but at a greater ultimate cost. It has been decided to make provision in the designs for the ultimate requirements; and the following table shows the length of the different sections of the canal in excavation in the lake, the river San Juan, and through the basins, and also the dimensions of prism for the same as now proposed: —

	Length, Miles.		
Canal in excavation, east side, ...	14.870		
Canal in excavation, west side, ...	11.160		
Six locks, both sides, ...	0.759	26.789	Total canal in excavation.
Basins of the Deseado, ...	4.848		
Basin of the San Francisco, ...	11.267		
Basin of Tola, ...	5.504	21.619	Total length of basins.
River San Juan, ...	64.540		
Lake Nicaragua, ...	56.500	121.040	
From the Atlantic to the Pacific, ...		169.448	Total length of route.

The dimensions of the canal in excavation in the several sections are as follows: —

	Length, Miles.	Width in Feet.		Depth, Feet.	Slope.	Area of Prism, Square Feet.
		Top.	Bottom.			
From Greytown to Lock No. 1, ...	9.297	288	120	28	3 to 1	5,712
From lock No. 1 to Eastern Divide Cut, . .	1.423	210	120	30	1½ " 1	4,950
Eastern Divide Cut, ...	2.917	100	100	30	0	3,000
In Eastern San Francisco basin, ...	1.233	210	120	30	1½ " 1	4,950
From Lake to Western Divide Cut, ...	1.565	210	120	30	1½ " 1	4,950
Western Divide Cut, ...	4.924	100	100	30	0	3,000
Western Divide Cut to Tola basin, ...	2.519	210	120	30	1½ " 1	4,950
Lock No. 5 to lock No. 6, ...	1.582	210	120	30	1½ " 1	4,950
Lock No. 6 to Brito harbor, ...	0.570	Variable.	Variable.	30	2 " 1	Variable.
River San Juan where dredged, ...	27.500	Variable.	125	Mean 28	Undetermined.	Undetermined.
Lake where dredged, ...	14.250	Variable.	150	30	Undetermined.	Undetermined.

THE EXCAVATIONS.

The character of the material to be removed, both wet and dry, has been accurately determined on the whole route by numerous borings penetrating to the bottom of the canal and on the site of the dams, embankments, and locks, to the depth required to ascertain in each case the nature of the foundations. In the harbor of Greytown and its approaches clean, sharp sand is the only material met with. From the harbor to lock No. 1 and through Benard Lagoon the materials are sand and sandy clay, underlying a thin, loamy stratum and decomposed organic matter, and from the lagoon to the lower lock, stiff clay. The harbor and this sea-level portion of the canal will be made with the floating dredge. Slopes of three horizontal to one vertical have been allowed in the estimates; but past experience gained in dredging by the company in the first mile of canal shows that the material stands perfectly for several months at a much less inclination, and in the excavation for the railroad through the stiff tenacious clay predominating in this region, the material stands nearly vertical. However, slopes of 1 1-2 to 1 have been estimated for. From the lower lock to the Divide Cut this hard clay, with occasional boulders, is the only material found by the boring tool on the axis of the canal throughout, and also at the site of the three locks and the embankment. This clay is impervious to water, and has a large sustaining power, so that no apprehension is felt as to the character of the foundations. In the deep cut the geological formation is clay, overlying solid volcanic rock. (See geological profile.) Diamond drill borings have been taken along the whole length of the cut to the bottom of the canal at intervals of about 1,000 feet; and the cores brought up settle beyond doubt the character of the material to be removed, and dispel all apprehension that this cut might be a repetition of the disastrous experience in the great Culebra cut at Panama. The slope allowed in clay is 1 1-2 to 1 and in rock 1-5 to 1 to the level of the water, and below that point vertical. In fact, there is no good reason why the whole rock excavation should not be made with vertical sides. In the Corinth Canal, where the excavation is longer and deeper and the rock less homogeneous and softer, a slope of 1-10 to 1 has been carried down to the water level, and the sides do not crumble or slide. From the Divide to Ochoa homogeneous clay has been found at all points; and, as shown in the preceding table, the standard section in soft material has been adopted throughout. At the site of the Ochoa dam gravel clay and rock in the order named are shown by the borings.

EMBANKMENTS AND DAMS.

The embankments in the valleys and on the crest of the confining ridges are proposed to be made water-tight of the clay, which is of excellent quality for this purpose, prevailing everywhere in those hills and valleys, but taken principally from the excavations. The embankments rise 8 feet above the water surface, with top widths of 12 feet if not over 8 feet high, 15 feet if not over 15 feet in height, and 20 feet for heights above 15 feet. Water slope, 3 to 1. Dry slope, 2 1-2 to 1. Top and water slopes to be paved with 2 feet of well-laid stones. Of these embankments, two in the valley of the Deseado and six in the San Francisco basin will be of considerable height, especially the latter, as the surface earth will be removed to form depths so as to insure a solid and secure foundation.

The maximum water pressure against the Deseado dams will be 45 feet, and in the San Francisco but little more than 60 feet, as water always lies on the surface or but little below it in the valleys. These embankments, intended to impound so large a volume of water, are important works; and in their construction sound judgment and great care must be exercised, but they present no more serious difficulties than have already been successfully met at many other localities. In a paper like this, details of construction which belong entirely to the specifications for the works cannot be treated at length; but it may be proper to remark that with good bottom to build upon and excellent material of construction, and with proper execution, no apprehension need be felt for the safety of works. The small embankments are numerous, it is true; but they deserve no special mention. They constitute a number of such ordinary jobs as the practical engineer is constantly called upon to handle.

The Ochoa and Tola dams are the keys controlling this great problem at the east and west ends of the summit level, and should not be passed without special notice, particularly so the former, in which a novel method of construction is contemplated. This work has been for years the subject of long study and careful consideration. The diversion of the river San Juan is well-nigh impossible; and construction by the usual methods, with either cut stone or concrete, of so important a work in opposition to the mighty power of the stream is a problem involving the most serious difficulties. It was at first proposed to build a stone dam upon a series of arches supported by tiers starting from the foundation, through which the river waters could flow freely during the construction of the main part of the structure, these openings to be closed by gates in the upper side when the upper part of the dam, its approaches and aprons, were completed; and then to be filled with masonry from the lower side, while the water was rising in the basin. This was, perhaps, as a practical solution, probably the best under the circumstances for that style of dam; but its execution would be tedious, difficult, and expensive, and there was to be always present an element of doubt not easy to eliminate as to the final success. The building of the foundations and pilaster for the support of the arches in constant contention with the whole river would be a most difficult undertaking, in which the items of time and cost would remain unknown quantities to its completion. Another idea has since been suggested, which seems to embody simplicity, economy, and safety. It consists in dumping from an aerial suspension conveyor large and small material properly assorted, across the river from bank to bank until a barrier is created sufficiently high and strong to arrest the flow and hold the waters at the required level: the body of the dam to be made up of large blocks of stone, weighing from 1 to 10 tons and smaller material to fill the voids. Its base will be quite broad as compared with the height, probably from 400 to 500 feet between the foot of the up-stream slope and the end of the apron. The top is estimated 30 feet wide, the rock up-stream slope 1 to 1, and the apron, or down-stream slope, 4 to 1, with the lower portion flattening down to 5 or 6 to 1. On the up-stream side small material, such as stone, fragments of gravel, clay, etc., selected as circumstances may require, will be deposited as the work advances, in sufficient quantity, as tight as wanted. It is not expected or even desirable to have a water-tight structure, the object sought being simply to oppose such an obstruction to the river as may be necessary to hold the waters at the required level. The minimum flow of the river is about ten times the water needed for working the canal. Consequently, 9-10 of it can be wasted with advantage. That the dam will eventually become tight there can be no doubt, as the small drifts and detritus forced in by the current will gradually fill the voids and consolidate the structure.

The method of construction will be quite simple. After protecting the abutments against possible erosion, large pieces of rock will be dumped in the bed of the stream from three or four cableways spanning the valley. The material should be distributed uniformly over the area under the main portion of the dam, commencing up-stream, and keeping up, as nearly as possible, an even level. Scouring will soon cause settling of the blocks into firmer soil, the upper level in the mean time being constantly raised by depositing more stone, while the small material is being forced by the current into the voids, and the overflow dislodging and rearranging the unstable blocks until they reach a final resting-place. This process to be continued until the resistance at the bottom becomes so great as to check scouring due to maximum pressure, when the dam will be carried up to the desired level. The river, in the mean time running over the mound, will readjust the material in, and adapt the apron to the necessary conditions of stability to withstand the effect of the fall, and carry off the water safely. If the dam is then raised so as to shut off a whole or the largest part of the river flow, which can by that time be discharged over the waste weirs, the structure will be permanent. If the river is not able to prevent the completion of this work, having, on the contrary, greatly contributed to its construction by a better distribution and consolidation of the material, now that the waters are diverted to another outlet, no fear need be entertained as to injury from that source. There may be some settlement and final readjustment of the component parts for some time after completion, but that can be easily remedied by depositing more material where needed. It is believed that this dam will be safer, as it is by far more economical, than a stone dam. An earthquake might cause serious damage to a masonry dam, but it can do no harm to this. On the contrary, it may add to its consolidation by bringing the parts in closer contact. There are no cemented joints to be opened, and a seismic disturbance would have a tendency to compact rather than to disintegrate the large mass. The rock for the dam will be brought by rail from the Divide, and delivered immediately under the wire cables, each one of which will be capable of handling and depositing about one thousand tons in ten hours. Consequently, the work can be completed in from four to five years, and, if it need be, in less time.

DEEPENING THE RIVER BED.

Another work of some magnitude is rock-blasting under water at Castillo and Toro rapids, amounting to about 400,000 cubic yards, the quantity to be determined by the side slopes found necessary. This work can be more economically done before the water is raised to the assumed summit level, but not before the lower section of the river has been raised by the Ochoa dam to the level of the upper rapids. Otherwise, the excavation in the upper rock ledge might cause an undue fall in the lake level, which would greatly interfere with navigation and the progress of the works in river and lake. This work presents no unusual difficulties, and the estimated cost of $5 per cubic yard will more than cover the cost. Above Toro rapids dredging will be needed in the bed of the river for about 24 miles. The average depth is 4 1-2 feet. The material is mud, clay, silt, and some loose boulders.

LAKE DREDGING AND PIERS.

At the east side of the lake dredging will be needed for about 14 miles from the outlet. The material is soft mud. The bottom width of the navigable channel here proposed is 150 feet, and the slopes 3 to 1. That side of the lake being sheltered from the prevailing north-east winds, no provisions are needed to protect the channel.

On the west side rock excavation in the lake amounting to 176 000 cubic yards is estimated for, also at $5 per cubic yard. This shore of the lake is exposed to the prevailing winds and waves, and the canal entrance must be protected by two piers projecting to deep water in the lake. They are proposed of crib, for which the native hard wood is admirably suited, and ought to be filled with stone from the excavations.

THE WESTERN DIVIDE.

From the lake shore to the Tola basin the excavation is in rock and clay, rock predominating through the Divide and clay in the valley of the Grande. Borings have been made from the bottom of the canal all the way to the sea, and the amount and character of the material to be removed accurately ascertained. From the basin to lock No. 6 clay is the material met with, and in the harbor area principally sand, with some mud and clay in the upper section.

THE LA FLOR DAM.

Numerous deep borings have been lately made at the site of La Flor dam, the results showing the solid rock ledge to lie much deeper than the first earth augur borings indicated, and that the original plans for that work must be materially modified to adapt them to existing conditions. It was contemplated to build this dam of rock-fill, on the same principle adopted at Ochoa; but the great depths of soft earth overlying the rock ledge, reaching in places to 96 feet below the valley, renders that plan inapplicable to this case, especially as here, unlike the San Juan, there is no large flow of water to assist in scouring the soft soil and in consolidating the fill. A dam with solid masonry core and earth slope is now proposed, spanning the valley with a length of about 2,000 feet, an extreme depth for 1,000 feet length, of 170 feet from crest to foundation of core, of which 70 feet will be above ground, and in addition, to core walls aggregating about 500 feet in length, penetrating the abutment hills to the rock ledge. Locks Nos. 4 and 5 will also rest in this bed of rock, forming part of the dam abutment, and connecting with the core wall at its western end. A waste weir, about 300 feet long, will be cut on the east side for the discharge of surplus water into the lower bed of the Grande. All this comprises a very important piece of work; but with good rock foundations and suitable material at hand, although its cost will be proportional to the magnitude of the enterprise, there is nothing to intimate serious engineering obstacles. Concrete will be used for the core walls and locks, the rock to be obtained from the Divide Cut. The earth for the puddle fillings and embankments can be had from the canal excavation or from the valley in the vicinity of the works.

THE LOCKS.

The locks are to be 650 feet long by 80 feet wide in the chamber. The lifts, as now proposed, will vary from 30 feet to 45 feet; and a change is under consideration by which the lift of locks No. 3 may be reduced to 40 feet and that of No. 2 increased from 30 to 35 feet. These high lift locks must not be regarded as necessary features of the project imposed by existing conditions. The gradual descent of the Pacific and Atlantic slopes to sea level after leaving the Divide Cuts, combined with the highly favorable topography of the country traversed by the canal, present many admirable sites for locks, the number of which could be so increased as to greatly diminish all the lifts. Such a plan, however, is not regarded as the best with a view to economy in original construction and future maintenance or in facility to the traffic through the canal. Of course, the matter of safety is of first consideration; but, with the exercise of proper care and engineering skill, the plans proposed can be successfully carried out. In the proposed plan for a lock canal at Panama lifts of 36 feet, with a possible maximum of 46 feet at high water, were adopted by the commission; but we cannot recall any ship-canal lock in actual operation with lifts approaching these figures. Yet, in working out the problem, the mechanical details, although necessarily of large proportions, have not so far developed any insurmountable difficulties either in construction or manipulation afterwards. The body of the lock is to be of concrete with cut stones in the mitre sills, the hollow quoins, and such angles as need protection from shocks. The gates will be of steel, to be manipulated by hydraulic machinery, of which we have an admirable example at the St. Mary's Falls Canal, where a lock 519 feet long by 80 feet wide and a lift of 18 feet is filled in 11 minutes and emptied in 8 minutes, the time consumed in opening or closing the gates more than 40 feet high being but 1 1–2 minutes. Another lock 800 feet long and 100 feet wide, with 21 feet minimum depth of water over the mitre sill, is here under construction and the time of filling and emptying the chamber by enlarging the size of the culverts.

TIME OF LOCKAGE.

The traffic passing through the canal will be limited by the time required for a vessel to pass a lock. In the St. Mary's Fall Canal vessels of over 3,000 tons' capacity are put through the lock inside of 20 minutes; and the writer has seen the whole operation of opening the lower gates, entrance of the steamer, filling the chamber, opening the upper gates, and exit of the vessel from the lock, inside of 19 minutes. In the Nicaragua Canal the operation of filling the lock and handling the gates will consume no more time, yet 45 minutes have been estimated as the average required for lockage. On that basis, and allowing but one vessel in each operation, the number that can pass the canal in one day is 32, or in one year 11,680. At the average tonnage of vessels using the Suez Canal, these would supply an aggregate of 20,440,000 tons. The traffic through the St. Mary's Canal lock in seven months in 1891 was nearly 9,000,000 tons, and in the same time in 1892 it exceeded 11,000,000 tons, or at the rate of 19,-000,000 tons annually; and the maximum capacity of the lock has not yet been reached. The vessels taking the Nicaragua route will be much larger than those upon the Great Lakes, and the tonnage per lockage will, consequently, be proportionately greater. For this reason a single system of locks has been proposed at the start; and, when the business requires it, parallel locks can be built, and the capacity of the canal doubled. Attention is called to the important feature of having all the locks connected with large basins, which will greatly facilitate the movement and allow the withdrawal of a large volume of water in a short time without injurious current or marked fluctuations of level in the basins. The question of water supply needs but a passing reference, the maximum amount required for the thirty-two lockages, on the improbable basis of one lock full for each operation,—namely, 127,400,000 cubic feet,—being but 1-10 of the minimum daily discharge of the lake.

TIME OF TRANSIT.

In estimating the time of transit from ocean to ocean, the speed in the excavated sections of the canal has been limited to five miles an hour, although in the Suez Canal steamers of 6,000 tons are allowed to move at six miles an hour and smaller vessels proceed at the rate of seven or eight miles an hour. In the lake and in the greater part of the river San Juan, vessels can travel with unrestricted speed hence:—

ESTIMATED TIME OF THROUGH TRANSIT BY STEAMERS.

	h.	m.
26,030 miles of canal at 5 miles an hour,	5	12
21,619 miles in basins at 7 miles an hour,	3	05
64,540 miles river San Juan 8 miles an hour,	8	04
56,500 miles in lake at 10 miles an hour,	5	39
Six lockages at 45 m. each,	4	30
Allow for detentions,	1	30
Total time of transit,	28	00

TRANSPORTATION FACILITIES.

Railroad lines have been projected from Greytown to the river San Juan at Ochoa, a distance of 37 miles, and from the lake to Brito, 18 miles. Of the former distance 12 miles are already finished, from Greytown towards the Divide, and are now in excellent condition and in operation in connection with the canal works. As soon as the rock is reached, the road will be extended across the Greytown Lagoon to the breakwater at the harbor entrance, upon which the rock from the excavation will be brought and dumped directly, as at Galveston, Texas.

PERIOD FOR CONSTRUCTION.

The time in which the canal can be finished will be controlled by the time needed to complete those important works without which the traffic cannot be established. It has been pointed out that the Ochoa dam can be finished in four or five years. The Tola dam, the locks, and the harbors can also be done in that time. The Western Divide Cut contains about 11,000,000 cubic yards of rock and earth; but the excavation is about nine miles long, and the greatest depth but 72 feet, consequently this work is of lesser magnitude than the Eastern Divide, in which a probable total of 12,000,000 yards will have to be extracted and removed from a trench less than 3 miles long at an average depth of 141 feet. It is therefore to this latter work that we will have to look for a limitation in estimating the time in which the whole route can be opened to the world's traffic. On the basis of 12,000,000 cubic yards, of which two-thirds will be rock, assuming six years' continuous work, at the rate of ten hours a day, there will be an output of 6,700 cubic yards per day. This amount of material can be lifted and landed on the cars by 22 overhead wire cables at the moderate rate of 300 cubic yards each per day, and can be hauled to the dump or place of destination by 112 train loads of but 120 tons each, or, say, 11 train loads an hour. About one-eighth of this will go as far as Ochoa, for the construction of the dam, and about the same amount for the breakwaters and the locks Nos. 1, 2, and 3. Of the balance, one-half will probaby be needed for the embankments in the valleys of the Deseado and San Francisco; and the rest can be deposited in the vicinity of the excavation, but a few hundred yards away. Allowing for repairs, accidents, and other unavoidable delays, it may be estimated that a plant comprising 30 cableways, with attachment and machinery, 50 locomotives, and 1,000 cars will be ample for this work. The above would be a rather heavy traffic to handle, if sent out over the main line; but, distributed as suggested above, with a large portion of it sent off on spur tracks from both sides of the three miles of excavations, to be deposited in the numerous ravines and valleys in the vicinity of the work, it does not look unmanageable. But, if need be, work can be carried on without interruption by the aid of electric lights. Therefore, as regards the disposition of material, six years seem to be ample; and, as to the work of digging and blasting, it will be admitted that the mind capable of organizing and carrying out the former will have no difficulty in mastering the latter. Consequently, the previous estimate that the canal can be completed in six years after the works are fairly started is adhered to.

On one section 2 1-2 miles one way of the Manchester Canal, now under construction, the contractor has taken out for two or three months continuously at the rate of 20,000 tons per day in one shift of nine hours. This includes ballasting, loading in wagons, hauling, and depositing. The plant employed consists of 59 locomotives and 1,400 wagons. The contractor has been much restricted and embarrassed in his operations by limited dumping grounds, which would not be the case in Nicaragua.

ESTIMATES.

In estimating the cost of the canal, the following prices per cubic yard have been adopted: —

Dredging, 20 cents and 30 cents. Excavation in earth, 40 cents. Excavation in rock, $1.50 and $1.25. Excavation under water, $5. Embankments, 40 cents to 70 cents. Concrete, $6 to $10. Rock fill, 50 cents. Breakwater, *pierre perdue*, $1.50. Grubbing and clearing, $100 per acre. Railroads, $60,000 and $25,000 per mile. Telegraph, $600 per mile. The total cost of the canal is estimated at $65,000,000, inclusive of 25 per cent. for contingencies, but exclusive of interest, commissions, and other charges not coming under the cognizance of the engineer, and on the basis that the work will be prosecuted with vigor along the whole line and without intermission.