

## FROM TEHUACAN TO OAXACA AND PUERTO ANGEL BY WAGON ROAD.

PLACES.	Altitudes.		PLACES.	Altitudes.	
	Metres.	Feet.		Metres.	Feet.
Tehuacan.....	1660.00	5446.38	Tierra Blanca.....	2000.00	6561.89
La Huerta.....	1480.00	4855.81	Rio Atoyac.....	1660.00	5446.38
Arroyo de Buena Vista.	1320.00	4330.85	San Pablo Huitzo.....	1700.00	5577.62
San Sebastian.....	1120.00	3674.66	Santiago Huitzo.....	1680.00	5512.00
Camino de Calipán....	1060.00	3477.81	Villa de Etla.....	1660.00	5446.38
Calaveras.....	960.00	3149.71	Dolores.....	1640.00	5380.76
San Antonio.....	900.00	2952.85	Panzacola.....	1540.00	5052.66
Hacienda de Ayotla..	860.00	2821.62	Oaxaca.....	1540.00	5052.66
Rio de Reyes.....	900.00	2952.85	San Agustin Juntas..	1530.00	5019.85
Tecomavaca.....	620.00	2034.19	Coyotepec.....	1600.00	5249.52
Rio Salado.....	600.00	1968.57	Cúspide.....	1900.00	6233.70
Campanario.....	730.00	2395.10	Santo Tomás Jaliera..	1830.00	6004.14
Organo.....	700.00	2296.67	Ocotlan.....	1720.00	5643.24
Pajarito.....	680.00	2231.05	Magdalena.....	1700.00	5577.62
Gavilan.....	600.00	1968.57	San Martin.....	1700.00	5577.62
Paraje Blanco.....	580.00	1902.95	Rio Coapa.....	1590.00	5216.71
Rio Seco.....	560.00	1837.33	Ejutla.....	1540.00	5052.66
Chonoslar.....	700.00	2296.67	Arrogante.....	1600.00	5249.52
Rancho de Urrutia...	620.00	2034.19	Chichovo.....	1840.00	6036.95
Rancho de Cuagulotal.	620.00	2034.19	Zopilote.....	1810.00	5938.52
Rancho de los Obos...	620.00	2034.19	Cúspide.....	1930.00	6332.23
Hacienda de Güendu-			Tlacuache.....	1840.00	6036.95
lain.....	620.00	2034.19	Tepehuaje.....	1780.00	5840.33
Rio Apoala.....	540.00	1771.71	Miahuatlan.....	1800.00	5905.71
Rio Tomellin.....	540.00	1771.71	Chapaneco.....	2230.00	7316.51
Balconcillo.....	680.00	2231.05	Agua del Sol.....	2400.00	7874.27
Rancho del Chilar....	660.00	2165.43	San José del Pacifico..	2600.00	8530.46
Infiernillo.....	660.00	2165.43	Garganta del Encino..	2800.00	9186.65
Don Dominguillo....	750.00	2460.72	Tres Cruces.....	3160.00	10367.79
Arroyo Dominguillo..	720.00	2362.29	Rancho de Canoas...	3000.00	9842.84
Arroyo de Nopala....	710.00	2329.48	San Miguel Xuchistepec	2780.00	9121.04
El Pochote.....	1240.00	4068.38	Rio de San José.....	2340.00	7677.41
Canton de Buena Vista.	1360.00	4462.09	Cerro de Santa Ana...	2720.00	8858.56
Cúspide.....	1500.00	4921.42	Cerro de San Pedro...	2500.00	8202.36
Puente de la Joya....	1400.00	3412.19	El Porvenir.....	800.00	2624.76
Venta Vieja.....	1600.00	5249.52	Garganta del Cerro de		
Paredones.....	1840.00	6036.95	la Pluma.....	900.00	2952.85
Llano del Timbre....	1900.00	6233.70	La Providencia.....	830.00	2723.19
Cieneguilla.....	2020.00	6627.51	La Soledad.....	750.00	2460.72
Portezuelo.....	2220.00	7283.70	San José Totoltepec...	530.00	1738.90
Las Trancas.....	2080.00	6824.37	Rio Chacalapa.....	340.00	1115.52
Carbonera.....	2160.00	7086.84	Pochutla.....	160.00	524.95
Ojo de Agua.....	2100.00	6889.98	Puerto Angel.....	0.00	0.00

THE VALLEY OF MEXICO'S DRAINAGE.<sup>1</sup>

Mexico is finishing a great work, the drainage of the valley where the capital city is located, which has required for its completion nearly three hundred years and many millions of dollars, and has cost the lives of hundreds of thousands of men. The necessity, importance,

<sup>1</sup> This article was published in the *Engineering Magazine* of New York for January, 1895 (vol. viii., No 4), but has since been revised and considerably enlarged.

and magnitude of this work, which will be classed among the grandest achievements of men, and the nearness of its completion, induce me to write this paper, which I hope will give some idea of its scope and purpose. I do not pretend to originality, as my work to some extent has been one of compilation from different monographs, which have appeared from time to time, and from some official publications of the Mexican Government.

*Topographical Conditions of the Valley of Mexico.*—The Valley of Mexico is an immense basin, of approximately circular shape with one extreme diameter of about sixty miles, completely bounded by high mountains, and having only two or three quite high passes out of it. No water drains out of the basin. The surface of this valley has a mean altitude above the sea of 7413 feet and an area of about 2220 square miles.

Mountain ranges rise on every side, making a great corral of rock containing dozens of villages and hamlets, with the ancient capital in the centre. In times past the fires of volcanoes licked up the earth, and such fires still live in the mammoth Popocatepetl, from whose great crater sulphur fumes and smoke with jets of flame have poured through the centuries.

The valley thus hemmed in with solid walls of rock had been an inland sea for many cycles, and during the early existence of man here the salt waters spread over a large extent of the depression. The waters have been gradually lessening by seepage and evaporation, and the Aztec pilgrims coming from the north in the fourteenth century, having received a sign that they were to build their queen-of-the-world city on a small island of the sea, set about building dikes and combating the overflow of the waters.

Evaporation is so excessive at certain periods of the year that malaria, consequent on drought, was far more dreaded by the inhabitants than the periodical floods, and thousands perished annually, so that proper drainage was an absolute necessity for the preservation of health.

*Work done by the Indians.*—Nearly fifty years before the discovery of America, which took place in 1492, Netzahualcoyotl, saw the necessity for a drainage canal, and commenced the work in 1450. He constructed an immense dike to divide the fresh from the salt-water lakes of the valley. The City of Mexico was at this time the centre of the Aztec nation, and was built on floating structures, like rafts, on the water in the numerous islets on the margins of the lakes, so that in the event of the water rising or the city being subjected to a state of siege, the whole city would float. Mexico City now occupies the site of the old Aztec capital.

The waters of these lakes were liable to disturbances of all kinds;

thus it is recorded by Prescott in his *History of the Conquest of Mexico*: "In 1510 the great lake of Texcoco, without the occurrence of a tempest or earthquake, or any other visible cause, became violently agitated, overflowed its banks, and, pouring into the streets of Mexico, swept off many of the buildings by the fury of its water."

When Cortez arrived in Mexico from Spain in 1519 to take possession of the country in the name of the King of Spain, he found, to his great surprise, the defense of the city admirably arranged, and an almost enchanting view of flowering islets forming the floating capital. Little towns and villages lay half-concealed by the foliage, and from the distance these looked like companies of wild swans riding quietly on the waves.

A scene so new and wonderful filled the rude heart of the Spaniard with amazement. So astonished was he at the extent of the water of Lake Texcoco that he describes it as "a sea that embraces the whole valley," but upon hearing that it was a lake, with a mean depth of a few yards, he gave orders to cut a way through the dike and destroy the aqueduct of Chapultepec. The central dike dividing the fresh from the salt water lake was of such dimensions as to serve Cortez as a roadway for his army.

Prescott, in the work before alluded to, page 297, says: "Leaving the mainland, the Spaniards came on the great dike or causeway, which stretches some four or five miles in length, and divides Lake Chalco from Xochimilco on the west. It was a lance in breadth in the narrowest part, and in some places wide enough for eight horses to ride abreast. It was a solid structure of stone and lime, running directly through the lake, and struck the Spaniards as one of the most remarkable works they had seen in the country."

Having cut the dikes and drained the lake, the "floating city" was at once besieged, and where originally stood the great temple of the Aztecs a Christian temple was afterward raised. The Spaniards, finding themselves in complete possession, proceeded to erect the new City of Mexico, and building on the plan adopted by them at home, they cut down the points of the floating islands and by gradual extension soon placed the town below the mean average level of the lake. Hence arose the great difficulties of the drainage of the Valley of Mexico.

One of the immense dikes built by King Netzahualcoyotl was ten miles long. It divided Lake Texcoco into two parts. Of the two lakes thus formed one was allowed to remain salt, but the other was freshened by letting only fresh water enter by the streams flowing in, the water for the use of the city being taken from this latter. Little by little the waters have subsided since that period, and have been fought back, until now they are confined to six great lakes—Chalco, Xochi-

milco, Texcoco, Xaltocan, San Cristobal, and Zumpango. Each of these lakes is fed by streams which have little volume during the dry season, but which in the rainy season swell to considerable size, and at times overflow the valleys. The lake of Zumpango was the most dangerous of these, for it received the waters of the Cuautitlan River,—a river draining a large area of country, and having during the rainy season a great volume of water. This river has been turned into the cut of Nochistongo, and has ceased to threaten Mexico and its environs with its overflow.

From these topographical conditions frequent floodings of the old Aztec city and of the Spanish capital, situated almost at the lowest point of the valley, were sure to come in times of unusually heavy rains. In early days, when the Aztecs lived in the middle of Lake Mexico, when their temples and wigwams were built on piles and the streets were often only canals, the periodical overflows from the upper lakes were a matter of small concern, though even then the Nahuatl engineers were called upon to protect the city by dikes. But when by evaporation, by filling in at the site of the city, by lessened waters, due to the fissures caused by earthquakes, Lake Mexico had disappeared, and the city had come to be built on the spongy soil, above all, when the short-sighted choice of Cortez had been confirmed and the capital of New Spain had come to stand on the ruins of the Aztec town, increasing rapidly in population and wealth,—it became a serious matter that on an average of once in twenty-five years the streets should be from two to six feet under water for an indefinite time.

*Work done by the Spaniards.*—From 1519 to 1553 the Spaniards were busily engaged in building Mexico, and another grand dike, similar to that built by Netzahualcoyotl in 1450, was formed around the city; this protection proved insufficient, for in 1580 another inundation took place. The Viceroy of the day, Señor Don Martin Enriquez de Almanza, assisted by engineers, engaged to find an outlet for the waters north of the valley. During the time they were thus engaged, important facts were gleaned respecting the River Cuautitlan, and its curious behavior at the foot of Nochistongo, whence it doubled its course at a certain altitude and ran toward Lake Texcoco, instead of into its own lake of Xaltocan. The scheme formed by Enriquez de Almanza to remedy this evil was kept in abeyance, as his services were required in Peru.

In the year 1604 a serious inundation attacked Mexico City. The Marquis de Montes Claros did all in his power to carry out the plan of Señor Don Martin Enriquez to relieve the rivers of the north and of the valley of the excess of water from the central and south lakes, which are of higher altitudes. The *pros* and *cons* of this plan were beset with many great difficulties, and respecting one of the methods

tried, mention must be made of a dike of great strength, constructed to prevent any excess or overflow of water from destroying the town of Zumpango and washing away its crops. This dike, which was to check the strong current of the river Pachuca, would also direct the river Cuautitlan to Mexico, direct the rivers north into Zumpango, and would inundate that verdant district, and probably submerge the town; whereas, to divert them into Lake Texcoco would submerge Mexico. To prevent this evil it was decided to make a tunnel; but here, as in all countries and in all ages, engineers, when engaged in any work of magnitude, and of a different character from that commonly known, always find theorists to offer objections, and thus stop the way to actual progress. This was the case in Mexico City.

In 1607 another inundation, spreading over the whole valley, occurred, and, as all the dikes and other defences were swept away, caused a panic of terror among the inhabitants. The Marquis de Salinas was then Viceroy at Mexico City, and determined to carry out the plan of Señor Don Martin Enriquez, being assisted by an engineer of great repute named Enrico Martinez, and also solicited and obtained the co-operation of Father Sanchez, of the Society of Jesus. These three men, after many consultations, formulated the plan of embracing the whole of the lakes of the plain into one main channel of detention, and an outlet as required to keep the same under such control as to have at all times an abundance of water for use. The plan, broadly speaking, was to draw off the water from the south lakes which are at higher levels to those of the north, and to make them serve, by the scour the velocity of the water would cause, to deepen the passage for their exit, and, at the same time, assist the making of the grand canal.

Great opposition to this plan was offered on the score of economy, and many insisted that the inundations were solely due to the waters of Cuautitlan and the freshets of Pachuca, and if these were directed north no more was needed, while the people of Zumpango tried to show that no more was needed to inundate their town and submerge the district. The Viceroy then requested Enrico Martinez to induce Father Sanchez to submit some modifications of his former scheme.

The plan was modified, and on November 28, 1607, Enrico Martinez started operations on the modified plan, and in about eleven months 6600 metres ( $4\frac{1}{10}$  miles) of tunnel, with a transverse section of 3.50 metres ( $11\frac{1}{2}$  feet) wide, and a depth of 4.20 metres ( $13\frac{3}{4}$  feet), was completed. At the same time other important drainage works were being made; the passage was opened from Boca de San Gregorio to Salto de Tula; this was 8600 metres ( $5\frac{1}{3}$  miles) long, as well as two canals as aqueducts  $6\frac{1}{2}$  miles long, one for Lake Zumpango and the other for the river Cuautitlan from Teoloyucan to Huehuetoca.

In December, 1608, in the presence of the Viceroy Don Luis de Velasco and the Archbishop of Mexico, Enrico Martinez inaugurated the outlet of the waters, the whole of the work just described being executed in one year. Humboldt tells us that fifteen thousand native Indians were employed on these works.

In spite of the great good these works brought to the people, there was an outcry for economy, but it is certain that other motives prompted the disturbance and the attempt to harass and hamper the Viceroy. The object was to prevent a grant of money from being made to pay for the lining of the tunnel with brick. This was found to be necessary, as the greater part of the work was excavated in marl, and the liberated waters ran with such velocity that the symmetry of the tunnel was soon destroyed, and its passage and usefulness lessened by the *debris* that obstructed the fairway. This state of things was brought so forcibly home to the objectors that a small sum of money was reluctantly granted, sufficient to patch up the tunnel in places where the rush of waters had made the most havoc, hydraulic cement or mortar being used, but the sum granted proved to be totally inadequate, and for want of more money the tunnel was rendered perfectly useless by falling obstructions. This occurred in the year 1609. Gossips and theorists then united to run down the scheme, although it was conceded that the work had averted a terrible inundation or submergence of Mexico City.

A few years elapsed before the question of continuing the works for the tunnel again caused excitement; but a general feeling grew up that the work of the tunnel should be continued. The opposition was strong enough to obtain the hearing of an appeal in Madrid, with the result that the Spanish Government in 1614 procured the services of a Dutch engineer, named Adrian van Boot, to proceed to Mexico City to examine and report on the canal works, and to submit a plan to remedy the evils. As the result of his labors he condemned the plan of Father Sanchez, and recommended that the old means of defence used by the Indians should again be adopted, and that dams and dikes should be thrown up at once. This report had the effect of annoying almost everybody, and was the means of much fruitless discussion. In this dilemma the Spanish Government, when appealed to, confessed they were unable to advise the Viceroy of Mexico what to do, but sent the Marquis of Gelves to Mexico to see into matters, and he, having unbounded faith in the ability of the Dutch engineer, Adrian van Boot, and hoping to keep money in the treasury, ordered Enrico Martinez to close up the tunnel completely, and to return the rivers to their natural courses; but before these orders were half executed the enormous rush of waters grew so alarming that he had to accept again Enrico Martinez's plan over that of Adrian van Boot. The

Marquis was soon after deposed, his place being taken by the Marquis de Cerralvo, whose first act was to set Martinez free at the request of the city council who provided him with means of continuing his work on the canal and tunnel. The Viceroy revoked his predecessor's order and issued another to open up the tunnel, and that with all speed, on his personal responsibility. Although Cerralvo gave these orders, he forgot to give Martinez the money to carry them out, and, as a consequence, the works remained in a deplorable condition.

The tunnel was blocked up by this cause, and Martinez was cruelly scored for not having done his work aright by the very ones who had refused to give him the necessary material for it. He bravely essayed to repair the damage, but the water-soaked condition of the ground gave no resistance for the building of the needed walls, while death mowed down the enslaved workers. They were crushed to death by the frequent cavings in of the loose soil, or were sent to the grave by the deadly damps. Finally, the charge being made that the builder was blocking up the tunnel in revenge, he was thrown into prison, where he languished for many months. As there was no one else available who could carry on the great work, he was afterwards released and again put in charge. It was then decided that, the tunnel being completely useless, the next thing to be done would be to make a great cut down to the tunnel and thus open it out. This entailed the making of an excavation fourteen miles in length with an average depth of one hundred and eighty feet and width of four hundred feet.

On June 20, 1629, the ever troublesome river Cuautitlan over flowed and inundated the north of the plain, and swept with it other streams into Lake Texcoco. In the September following the increase of the water was greater than ever had been known. The city was so suddenly and completely submerged that thirty thousand persons perished, the bodies floating about the streets for some time after. The destruction of property and life, consequent on the inundation, was so great generally, and affected the tunnel to such an extent, that during a period of five years there was scarcely any reduction in the height of the water, and the water in the city remained during all this time as high as the second story of the houses; the slight difference in the height of the water being caused by evaporation.

The Spanish Government at Madrid gave orders to change the capital to a better and more secure site. To this suggestion the citizens demurred, saying, in effect, that to insure complete security an outlay of only \$3,000,000 was necessary, this being the estimated cost of completing the tunnel, whereas to build a new city would involve an outlay of \$50,000,000, with a loss of another \$50,000,000 in leaving the old one.

Several plans were now submitted in opposition to that of Enrico

Martinez, and one by Simon Mendez was accepted, his plan being to direct all the waters of the valley by one canal into the neck of the Tula, the spot selected by Martinez for his outlet. It was soon discovered that the plan of Simon Mendez was far too costly, and as the money that could be spared was practically melting away without perceptible progress being made, Enrico Martinez was again requested to carry out the work as arranged with Father Sanchez.

The next Viceroy, the Marquis of Cadereita, was most desirous to see the work of the tunnel pushed on; but however enthusiastic he may have been, lack of funds prevented him from giving effect to his desires. The work continued very slowly, Martinez being unable to do any work at the tunnel, and he contented himself with improving the canal by lining it in bad places with cement. Martinez struggled on for thirty-seven years with this work, and died unnoticed and uncared for. All trace of his place of final rest was lost.

In 1637 an earthquake made sad havoc with the tunnel works, and for lack of funds no repairs could take place; but when funds were obtainable workmen could not be procured, the earthquakes and inundations having carried off many thousands of these poor fellows. The survivors lacked heart to return to such an unfortunate and, as they thought, accursed work.

In the year 1640 the work was being pressed on by men from the prisons, under the direction of the Franciscan monks, and carried on, with varying results, in this way for thirty-five years, until Señor Don Martin Solis was made head of the municipal council. He being an avowed enemy to the Franciscans, sent them away, and undertook the superintendence of the work himself; but his method of treating the prisoners was so harsh and cruel that they broke out into open revolt, and the works were threatened. Therefore, to save the works and his own life, he consented to the return of the Franciscans. It is estimated that up to this time some two hundred thousand men lost their lives on this work. The Franciscans steadily, but slowly, worked on, always with a very limited exchequer, until 1767, when there remained some 1935 metres (1½ miles) still to be completed. A contract was entered into to finish this work in five years for \$800,000; but instead of five years it took twenty-two years, and, instead of 8 metres (25 feet wide), as contracted for, it was only 3 metres (9 feet 10 inches) wide.

The Spaniards continued the work in other hands for one hundred and fifty years before the task of opening the cut was completed. Spasmodic work for a century and a half led at last to the accomplishment of this project in 1789. The old tunnel of Martinez is now a gigantic trench from 30 to 160 feet in depth and some 300 feet broad in some places, and is known as the Tajo de Nochistongo. The immediate vicinity of the workings was depopulated of its native inhabit-

ants by the insatiable demands of the killing labor, and recruits were then drawn from Puebla and other thickly populated Indian centres. Great prison barracks were built on the bare hills, and here all the criminals were sent to enter the work. The ones in charge were indifferent with regard to the lives entrusted to their care, and the slaughter, of which scant record remains in the parish burial books, and which resulted from a combination of defects in appliances for both the safety and the comfort of the workmen, was terrific. As the burial trenches were filled with new dead, the depths of the cut were tenanted by new laborers.

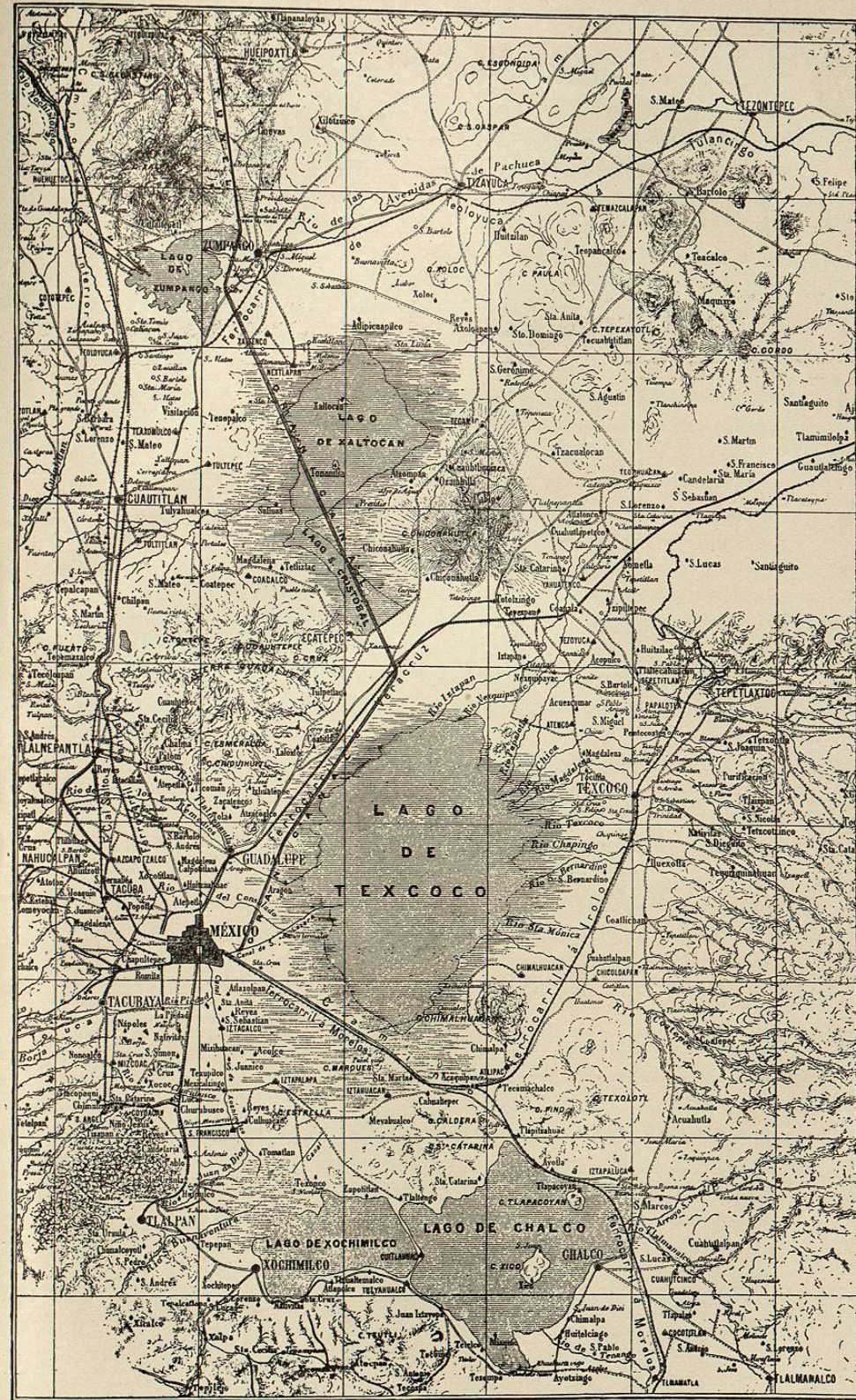
The victims of three years of bondage numbered fully two hundred thousand ere the work was done. Yet the results were but slight, only the excess of water from the highest lakes and streams being carried off. However, the danger from inundations of the city has been very materially decreased by the Nochistongo opening, and no more deluges have occurred since its completion.

Still the fact that the bottom of the cut was thirty feet higher than the surface of Texcoco, the lowest lying of the lakes, left the city in danger of inundation, as Lake Texcoco is constantly filling up at the rate of one and one-half inches a year and is now but a few feet below the level of the main plaza of the city.

The drainage works had long been a heavy burden upon the Mexican treasury. Up to 1637 Bancroft estimates that \$3,000,000 had been expended. Up to the year 1800 the outlay had reached \$6,247,670. Up to 1830 the total expenditure was \$8,000,000.

*Work done by the Mexican Government.*—The problem which the Mexican Government had to face was very different from that which confronted Martinez in 1607. The question of preventing submergence is practically solved. The work of Martinez, unsatisfactory as it was, did a great deal to solve it. Since his day the area of the lakes has been gradually diminishing. The rapid evaporation in the rarefied air and under the direct sun of the valley partly accounts for this. Twice the water in Lake Texcoco has almost entirely disappeared, leaving only a sea of mud and a small pool. The great problem which the Mexican Government has now solved is not how to prevent an inflow of water, but how to provide an outlet for sewage. The danger to be averted was not that of drowning, but that of dying from the plague.

Lake Texcoco more than any other now menaces the security of the capital. The unwise cutting down of forests since the Spanish conquest permits the waters pouring down into the valley to bring with them annually great quantities of alluvial matter, which have so much raised the lake bottom and the water level that inundations have been of frequent occurrence. The general level of the City of Mexico is only 6.56 feet above the surface of the lake. The rainy season lasts



MAP OF THE VALLEY OF MEXICO, SHOWING THE CANAL AND TUNNEL.