GROUND-WATER STUDIES IN THE PROVINCE OF COQUIMBO, CHILE.

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INTRODUCTION:

During October 1946 and again in October 1947 the writer made reconnaissance studies of the ground-water resources of some five areas in the Province of Coquimbo. The writer was accompanied during the first field trip by Sr. Mariano Allende U. and during the second trip by Sr. Joaquin Undurraga C., engineer of the Corporación de Fomento de la Producción.

The areas studied include the Quilimarí valley, the Quebrada of Aucó, the Tongoy area, the Lagunillas valley, and the Quebrada of Los Choros. The object of the studies was to determine the availability of ground water, and the feasibility of developing such water for irrigation by means of wells or other captation structures. The general location of the areas visited is shown in sketch map No. 1.

The Province of Coquimbo lies between latitudes 29° and 32° south and covers an area of some 39,889 square kilometers. The largest cities with their respective populations are La Serena (21,742); Coquimbo (18,863); Ovalle (14,897); and Illapel (6,085). The province occupies a large part of that region of Chile known as the "Norte Chico" or the region of the transverse valleys. The region within the province is largely a rugged, mountainous highland that rises steeply from the Pacific coast to elevations of some 4,000 to 4,500 meters along the crest of the Andes 90 to 160 kilometers inland.

The principal fluvial systems of the province are those of the Rio Elqui, the Rio Limarí, and the Rio Choapa. These streams are formed by the confluence of numerous minor tributaries that rise on the western slopes of the Andes. They flow through deep gorges and narrow, winding valleys cut through the highlands of the region. Near the sea the major streams are bordered by extensive fluvial terraces that may extend inland for as much as 30 to 40 kilometers.

In Coquimbo province practically all of the annual precipitation occurs during the winter months, that is, from May to September. Due to climatic factors the precipitation increases gradually from north to south. Near the northern limit of the province the average annual precipitation is of the order of 100 mm. At La Serena it is about 160 mm., and at Combarbalá, approximately 320 mm. The precipitation also increases with altitude. Near the coast the precipitation on the ridges may be twice as much as that in the adjacent valley bottoms. On the higher slopes of the Andes at elevations above 4,000 meters, the annual precipitation may be of the order of 750 to 1,000 mm. Snowfalls are common during the cold months at elevations above 2,500 meters, but below that elevation most of the annual precipitation falls as rain.

The geologic formations that occur in Coquimbo Province range in age from the Pre-Cambrian to the Recent. The oldest rocks in the province are of metamorphic origin. They include gneiss, schist, and phyllite of

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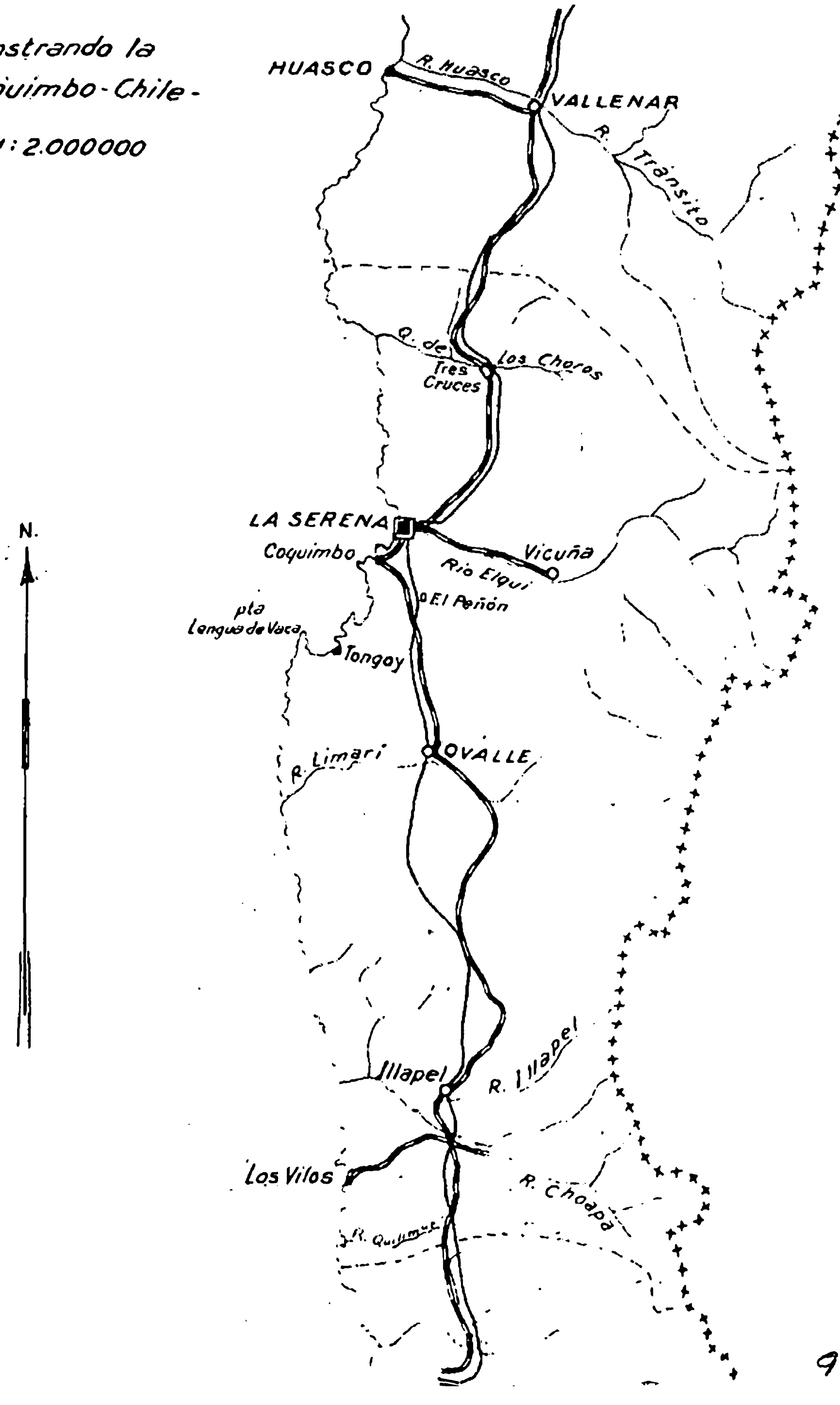
Escala 1: 2.000000



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probable Pre-Cambrian age. These rocks occur only in very limited areas - notably in the Altos de Talinay from the Punta Lengua de Vaca south to the mouth of Río Limarí and in a small zone just north of the mouth of Río Choapa.

Still younger are upper Triassic rocks of volcanic and marine sedimentary origin. They include quartz-porphyry lava flows intercalated with thin-bedded marine shales and limestones. They occur in a narrow band some 2 to 5 kilometers wide that extends along the coast for about 60 kilometers in the region of Los Vilos and Quilimarí.

The "Formación Porfiríticas" of upper Jurassic and lower Cretaceous age underlies fully two-thirds of the area of the province. It occurs in practically continuous outcrop in the Andean region and in the tranverse ridges of the central part of the province. The formation consists of a heterogeneous series of volcanic rocks - chiefly interbedded tuff, breccia, agglomerate, and porphyrite lava flows. Locally marine limestone, sandstone, and shale are intercalated with the volcanic rocks.

Stretching along the coast of the province is an irregular strip some 20 to 50 kilometers wide of intrusive rocks of probable upper Cretaceous age. These rocks cross-cut formations of older geologic age. They consist chiefly of granodiorite and diorite with local differentiations of granite and gabbro.

Along the lower courses of the major streams are fluvial terraces of clay, sand, and gravel that grade into marine limestone, clay, and sand in terraces along the coast line. These deposits are of probable Pliocene age and are most extensively developed to the south of the Bay of Tongoy, in the vicinity of the Bay of Coquimbo, and along the lower course of the Rio Limarí.

The youngest formation in the province includes Pleistocene and Recent deposits of unconsolidated clay, sand, and gravel that fill the lower parts of the larger valleys.

With respect to their water-bearing properties the Pliocene and older rocks have similar characteristics. They form the dissected highland areas and are therefore generally above the zone of saturation and rather thoroughly drained. Some ground water circulates through these rocks - chiefly along joints and fracture planes or in surficial mantles of disintegrated rock. Such water may sustain small springs or may supply domestic wells. However, in general, the quantities of water stored in these rocks are of secondary importance for irrigation.

The Pleistocene and Recent valley fill contains unconsolidated materials that are generally quite permeable and that may yield considerable water to irrigation wells. The occurrence and availability of ground water for irrigation in each of the areas visited are described beyond.

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QUILIMARI VALLEY

HYDROGRAPHIC AND TOPOGRAPHIC FEATURES:

The Rio Quilimarí rises on mountainous ridges at elevations of 1,500 to 2,000 meters above sea level and flows westward some 45 kilometers to the sea. In its upper course it follows a winding canyon cut 400 to 800 meters below the bordering highlands. A short distance upstream from Guangualí the stream enters a narrow alluvial valley. This continues downstream to the sea with an average width of about 300 to 600 meters. Pronounced narrows occur about 2 kilometers upstream from Guangualí and again about 5 kilometers upstream from Quilimarí. In the first case the alluvial valley is only about 50 meters wide and in the second, only 60 meters wide.

From Guanguali downstream to the sea the alluvial valley is bordered by narrow fluvial terraces about 25 to 30 meters above the Rio Quilimarí.

The Rio Quilimarí is an ephemeral stream that carries only the runoff of winter rains. This water is retained for irrigation in the dry season by a small reservoir located a few kilometers downstream from Tilama. The water is delivered to irrigated lands several kilometers downstream by means of a pipe line and canal.

GEOLOGIC FEATURES:

From the coast for several kilometers inland, the borders and bedrock floor of the alluvial valley are formed by glassy lava flows of quartz porphyry intercalated with thin-bedded, dark-gray, marine shales and limestones. These rocks are considered to be of probable upper Triassic age.

In the vicinity of the reservoir the valley is cut in rocks of the "Formación Porfirítica" of upper Jurassic and lower Cretaceous age. Here the formation includes chiefly porphyrite lava flows intercalated with tuff and breccia.

Crosscutting the older rocks are dikes and small masses of intrusive rock of upper Cretaceous age. Near Tilama and Guangualí these rocks are chiefly coarse-grained granite and granodiorite.

During middle Tertiary time the Río Quilimarí cut a deep valley in the Cretaceous and older rocks. Later in Tertiary time the continental margin was depressed. As a result the Rio Quilimarí filled the lower course of its valley with stream deposits of sand and gravel eroded from the headwater areas. At the same time a platform of marine abrasion was cut by wave action to a position a few kilometers inland from the present coast line.

In late Pliocene or early Pleistocene time the continental margin was uplifted, and the Rio Quilimarí cut down through the stream deposits and into the underlying bedrock. The uneroded remnants of the stream deposits were left as fluvial terraces some 25 to 30 meters above the present stream channel. Near Guangualí the terrace deposits form a mantle no more than a few meters thick on bedrock, but near Quilimarí the deposits may be 25 meters or more thick.

In late Pleistocene time the continental margin was again depressed or sea level rose, and the Rio Quilimarí again began to deposit sand and gravel. This cycle of deposition continues to the present.

The old stream deposits that underlie the terraces range from a few meters to more than 25 meters thick. They consist of poorly sorted, weathered, gravel and sand. The pebbles are chiefly of quartz, porphyrite, and granite.

The young stream deposits occur beneath the present alluvial valley of the Rio Quilimarí. They are composed chiefly of clean, fresh gravel with some sand. Near Guangualí the stream deposits consist of cobble and boulder gravel, but farther downstream the gravel decreases in size and sand becomes increasingly abundant in the deposits.

GROUND-WATER FEATURES:

The ground water in the Quilimarí valley comes entirely from precipitation that falls within the drainage basin of the Rio Quilimarí. In the higher parts of the basin the precipitation may be of the order of 400 mm. annually, but in the lower parts of the valley it may be no greater than 200 mm.

The Triassic, Jurassic, and Cretaceous rocks that form the valley walls and the bedrock floor beneath the young stream deposits have low permeability, and little capacity to store or to yield water to wells or springs in significant quantity. The old stream deposits that form the terraces are moderately permeable but are almost completely dissected and thoroughly drained. They are therefore not likely to contain ground water in important quantity.

The young stream deposits of the alluvial valley are moderately to highly permeable. The lower parts of these deposits are saturated with water. Each year during the winter rainy season this saturated zone receives replenishment chiefly by infiltration from the surface run-off of the Rio Quilimarí. Due to the presence of the dam near Tilama the run-off of the upper part of the basin is retained, and therefore may not pass downstream to the zone of saturation in the young stream deposits of the alluvial valley. However, infiltration does occur from the run-off in small tributaries that enter the valley below the dam.

The ground water in the young stream deposits moves down the valley along the slope of the water table which is approximately parallel to the channel of Rio Quilimarí. In the two narrows located upstream from Guangualí and Quilimarí, the water table rises to the surface in springs and marshy tracts. In the dry stretches of the alluvial valley between the narrows of Guangualí and the sea, the water table is generally only a few meters below the surface. At the village of Guangualí, which is located on a low terrace, the water table is at a depth of 7 to 8 meters in shallow domestic wells. The young stream deposits here consist of permeable cobble gravel with sand.

The ground water in the alluvial valley of Quilimarí is used to limited extent for domestic and stock use by shallow dug wells, but apparently no attempt has been made to develop it for irrigation.

CONCLUSIONS AND RECOMMENDATIONS:

A small ground-water underflow moves downstream through the young stream deposits of the alluvial valley. It is not likely that the total underflow through these deposits is greater than a few tens of liters per second. The dam near Tilama cuts off the important sources of water in the upper watershed. The entire drainage basin of the Rio Quilimarí has a relatively small area and a low rainfall. For these reasons a larger underflow than that estimated is not to be expected.

A part or all of the underflow in the young stream deposits could be recovered by an impervious curtain or cut-off wall constructed either at the narrows 2 kilometers upstream from Guanguali or 5 kilometers upstream from Quilimarí. At either site the impervious curtain would need to be of the order of 50 meters wide by perhaps 10 to 15 meters deep. The water developed in this manner could be delivered by gravity in canals to irrigated lands.

In the vicinity of Guanguali modest supplies of water for the irrigation of chacras of a few hectares extent could be develcped from wells in the young stream deposits. It is estimated that simple wells would have to be dug or drilled to depths of 10 to 15 meters and might be expected to yield of the order of 10 lts./sec. with pump.

QUEBRADA OF AUCO

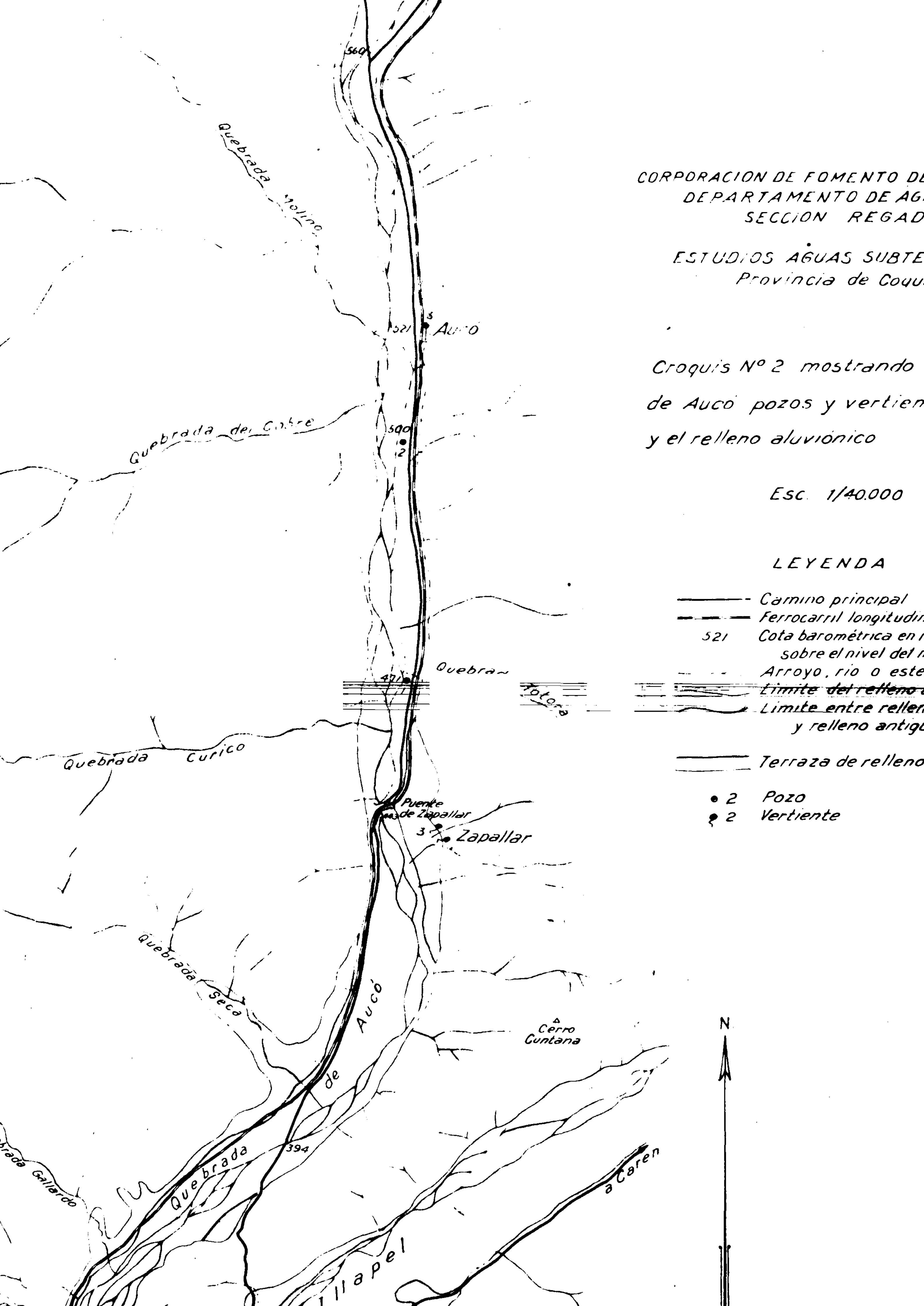
HYDROGRAPHIC AND TOPOGRAPHIC FEATURES:

The Quebrada of Aucó is a tributary of the Río Illapel. The confluence of the two valleys is about 1½ kilometers northeast of the city of Illapel. (See sketch map No.2.) The quebrada is formed by two principal tributaries - the Quebrada of Los Hornos and the Quebrada of Chillán. The former rises in highlands about 35 km. north of Illapel at elevations of approximately 1,500 m., and the latter rises some 45 km. northeast of Illapel at elevations of about 2,000 m.

The Quebrada of Los Hornos is cut in bedrock from its source to its junction with the Quebrada of Chillán. The latter quebrada enters a narrow alluvial valley some 8 km. upstream from its junction with the Quebrada of Los Hornos.

From this junction at an elevation of about 560 m., the Quebrada of Aucó follows an alluvial valley some 400 to 800 m. wide to a junction with the Río Illapel at an elevation of about 340 m. Through this stretch of approximately 12½ kilometers the average gradient of the valley floor is about 1.7%. (See profile No.1)

The Quebrada of Aucó is an ephemeral stream that carries only the run-off of the winter rains that fall on its watershed. Such run-off usually occurs in flash floods during the months of May to September. During the dry season both of the principal tributaries have small perennial flows sustained by springs, but even these may disappear in drought years. On Nov. 4, 1946 the flow of the Quebrada of Chillán some 10 km. above the Quebrada of Aucó was 6 lts./sec., and the flow of the Quebrada of Los Hornos 2 km. from the junction was 7 lts./sec.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2 Vertiente
Quebrada Molino
Quebrada del Cobre
Quebrada Curico
Quebrada Totora
Quebrada Seca
Quebrada de Aucó
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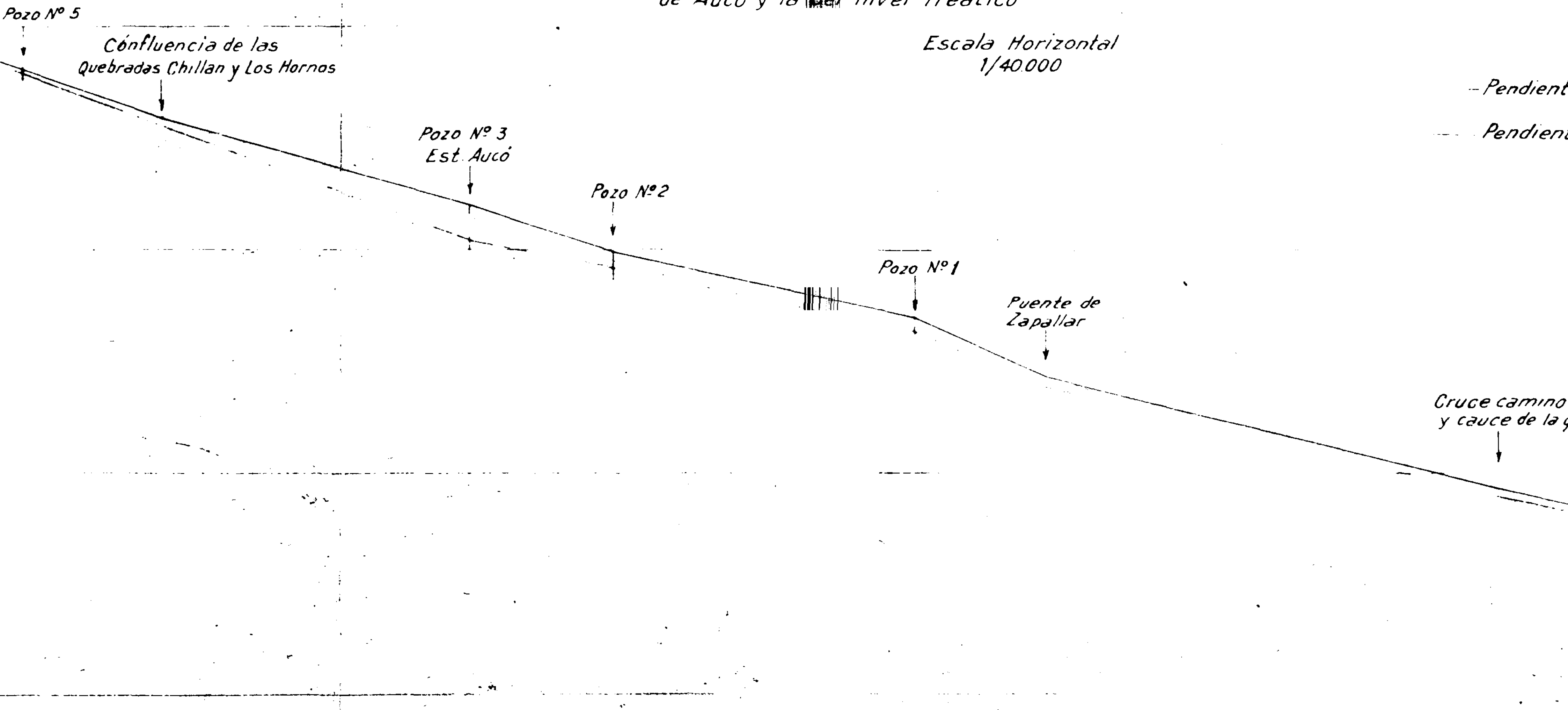
PERFIL N° 1

Perfiles mostrando la relacion entre la pendiente del cauce de la Quebrada de Aucó y la del nivel freático

Escala Horizontal 1/40.000



GEOLOGIC FEATURES:

The Quebrada of Los Hornos and its tributaries are cut entirely in rocks of the "Formación Porfirítica". The upper part of the drainage basin of the Quebrada of Chillán lies in the same rocks. The "Formación Porfirítica" in this region consists chiefly of massive, dark-gray flows of porphyrite lava intercalated with beds of indurated tuff.

Cross-cutting these rocks in the region of Illapel is a large intrusive mass of upper Cretaceous granodiorite and granite. These rocks form the sides and bedrock floor of the Quebrada of Aucó.

The Quebrada of Aucó first formed its course in the Cretaceous and older rocks by erosion during middle Tertiary time. Later due to rising base level of the Rio Illapel, the Quebrada of Aucó was filled with the silt, sand, and gravel eroded from its upper watershed.

In late Pliocene or early Pleistocene time the base level of the Rio Illapel lowered, and the Quebrada of Aucó was cut through the alluvial fill and into the underlying bedrock. In the process of downcutting remnants of the alluvial fill were left as narrow terraces 10 to 12 meters above the present stream channel. The extent of these terraces is shown between the green and yellow lines in sketch No.2.

Due to the rising base level of the Rio Illapel in late Pleistocene time, the process of filling in the Quebrada of Aucó was renewed and has continued to the present. In this manner the young alluvial deposits were formed.

GROUND-WATER FEATURES:

All of the ground water in the Quebrada of Aucó comes essentially from the precipitation that falls within its drainage basin. Practically all of the annual precipitation occurs in the months of May to September. This averages perhaps 350 mm. in the highest parts of the watershed, but no more than 200 mm. in the lower parts.

The rocks of the "Formación Porfirítica" generally have low permeability and small capacity to store ground water in important quantity. However, in the drainage basin of the Quebrada of Los Hornos and the Quebrada of Chillán are many small springs that rise from tabular partings in porphyrite beds. Most of these springs, individually yield less than one-half liter per second. In the aggregate, however, they sustain the dry-season flows of these two quebradas.

The upper Cretaceous intrusive rocks of granite and granodiorite when fresh have low permeability. However, a thin mantle of disintegrated rock known as arkose or "maicillo" has moderate permeability and capacity to store water and to yield it to wells and springs. In the Quebrada of Gallardo (see sketch map No.2) are many small springs that issue from "maicillo". The aggregate discharge of these may be of the order of 3 to 5 lts./sec. At Zapallar are two small springs (No.3) issuing from "maicillo". The combined flow of the two is about 0.25 lt./sec. It is used to irrigate a small grove of lemon trees.

The old alluvial deposits of the terraces (between green and yellow lines in sketch map No.2) are composed of poorly sorted silt, sand, and gravel. They are considerably disintegrated by weathering. For these reasons they have only low to moderate permeability. Moreover, they are completely dissected and thoroughly drained. Therefore, they are not likely to contain ground-water in significant quantity.

The young alluvial deposits (between yellow lines in sketch map No.2) consist of fresh and fairly well sorted gravel with sand. Near well No. 4 these deposits consist entirely of cobbles and boulders of granite and porphyrite. Far~~t~~ther downstream near well No.1 the deposits consist of cobbles and boulders up to 80 cm. in diameter with some coarse sand.

The young alluvial deposits of the Quebrada of Aucó are moderately to highly permeable. In their lower part is a saturated zone whose upper limit is the water table. The saturated zone receives replenishment chiefly by infiltration from floods that pass down the quebrada during the rainy season and to lesser extent by the spring-fed flows of tributary quebradas that seep into the young alluvial deposits during the dry season.

The ground water moves slowly through the young alluvial deposits down the slope of the water table to the Rio Illapel. Near the mouth of the Quebrada of Aucó is a constriction in the young alluvial deposits caused by a small granite nubbin. As a result of this constriction a part of the underflow of the quebrada is forced to the surface in spring No.1. The flow of this spring on Nov. 4, 1946 was estimated at 15 lts./sec. From well No.4 to the mouth of the quebrada the water table ranges from less than one meter to some 17 meters below the surface. The relation between the surface channel of the quebrada and the water table are shown graphically in profile No. 1.

The ground water in the young alluvial deposits of the Quebrada of Aucó has been developed for limited irrigation. Well No.2 (see table 1) yields 14 lts./sec. with centrifugal pump. Well No.1 which yields approximately the same quantity of water is used to irrigate a grove of lemon trees near Zapallar. Well No. 4, which produces a few liters per second with a small centrifugal pump, also irrigates a small grove of orange and lemon trees.

The quantity of ground water that moves down the Quebrada of Aucó through the young alluvial deposits is probably not large. As based on empirical observations it is estimated that the total underflow is not greater than 50 lts./sec. and perhaps much less. Considerable variation in the quantity of the underflow might normally be expected between the wet and dry seasons.

CONCLUSIONS AND RECOMMENDATIONS:

The strip of young alluvial fill in the quebrada has a poor, gravelly soil difficult of cultivation. Moreover, this strip is subject to the inundations of floods that pass down the quebrada. The terrace remnants of old fill (shown between the green and yellow lines in sketch No.2) have an excellent cultivable top soil. The two most favorable strips are (1) that near Zapallar and (2) that between the mouth of Quebrada Seca and Quebrada Gallardo.

TABLE 1.

DATA ON WELLS IN QUEBRADA OF AUCO.

November 4, 1946.

Well No.	Name of owner or place	Depth (meters)	Depth to water level (meters)	REMARKS
1	Zapallar	6.00	5.95	Under construction. In cobble and boulder gravel with coarse sand.
2	About one Km. S.of Est.Aucó	12.30	6.80	Yields 14 Lts./sec. with centrifugal pump. Irrigates grove of lemon trees.
3	Estación Aucó	19.40	16.40	Double-action lift pump. In coarse cobble gravel.
4		6.30	4.50	Small centrifugal pump. Irrigates small grove of lemon and orange trees.
5		~~1~~6.00	~~6~~1.00	Destroyed. Formerly yielded 20 lts./sec. ± and used for washing gold ore.

DATA ON SPRINGS IN QUEBRADA OF AUCO.

November 4, 1946.

Spring No.	Name of owner or place	Flow (lts/sec.)	Water-bearing material	REMARKS
1	At mouth of Quebrada of Aucó	15	Gravel with sand	A part of underflow in young alluvial deposits. Rises to surface because of bedrock constriction.
2	In Q. of Chillán	1.5	" "	Rises from young alluvial deposits in channel of quebrad
3	Zapallar	0.25	"Maicillo"	Two spring heads about 100 m. apart. Rise from disintegrated Cretaceous granite. Irrigate small grove of lemon trees.

These strips could be irrigated by either of two means - (1) by wells located in the young alluvial deposits at points just upstream from the irrigable areas or (2) by transverse cut-off walls or infiltration galleries constructed across the quebrada and below the water table. With wells located upstream from the irrigated areas, it would be necessary to pump the water to the surface where delivery to the irrigated tracts could be made by gravity through pipe line and/or canal. It is estimated that simply constructed wells dug or drilled to depths of 15 to 20 meters in the young alluvial fill near Zapallar and near the mouth of Quebrada Seca should yield of the order of 15 to 20 lts./sec. with pump.

Ground water for irrigation could also be developed by means of transverse cut-off walls or infiltration galleries. In the case of the former it would be necessary to construct an impervious curtain from the surface to a depth of 5 to 10 meters below the lowest normal stage of the water table and for at least two thirds of the width of the quebrada (about 300 to 500 meters).

Possibly more economical but equally effective would be a transverse infiltration gallery constructed at a depth of some 5 to 10 meters below the lowest position of the water table. For greatest effectiveness, a gallery some 200 to 300 meters long construded across the quebrada would be required.

Because of the relatively steep gradient of the quebrada, the water collected by cut-off walls or infiltration galleries could be delivered to the irrigated lands entirely by gravity through pipe line and/or canal.

TONGOY AREA

HYDROGRAPHIC AND TOPOGRAPHIC FEATURES:

The Tongoy area as discussed in this report includes the extensive plain lying to the south and east of Tongoy Bay to the east of the Altos of Talinay, and to the northwest of the Panulcillo hills. (See sketch map No.3). This plain rises from sea level in four narrow marine terraces to an elevation of some 100 meters about 2 km. inland from Tongoy Bay. From the 100 meter contour the plain rises evenly to the south and east to elevations of approximately 200 meters along the borders of the surrounding highlands. The plain is traversed by five large quebradas that rise in the bordering highlands and drain north and west to Tongoy Bay. These quebradas are incised some 30 to 90 meters below the surface of the plain.

With the exception of the Quebrada of Pachingo, all of the quebradas that drain the Tongoy area are ephemeral. They carry only the run-off that results from rains that fall in the area during the months of May to September. The Quebrada of Pachingo is an intermittent stream. Characteristically, it has several, perennial, spring-fed stretches separated by dry stretches. The flow in the spring-fed stretches is usually only a few liters per second. The Quebradas of Tongoy and Salinas also have short perennial, spring-fed stretches for 1,300 to 1,500 meters inland from Tongoy Bay.

GEOLOGIC FEATURES:

The Altos of Talinay that border the plain of Tongoy to the west are formed of metamorphic rocks - chiefly gneiss, schist, and phyllite.

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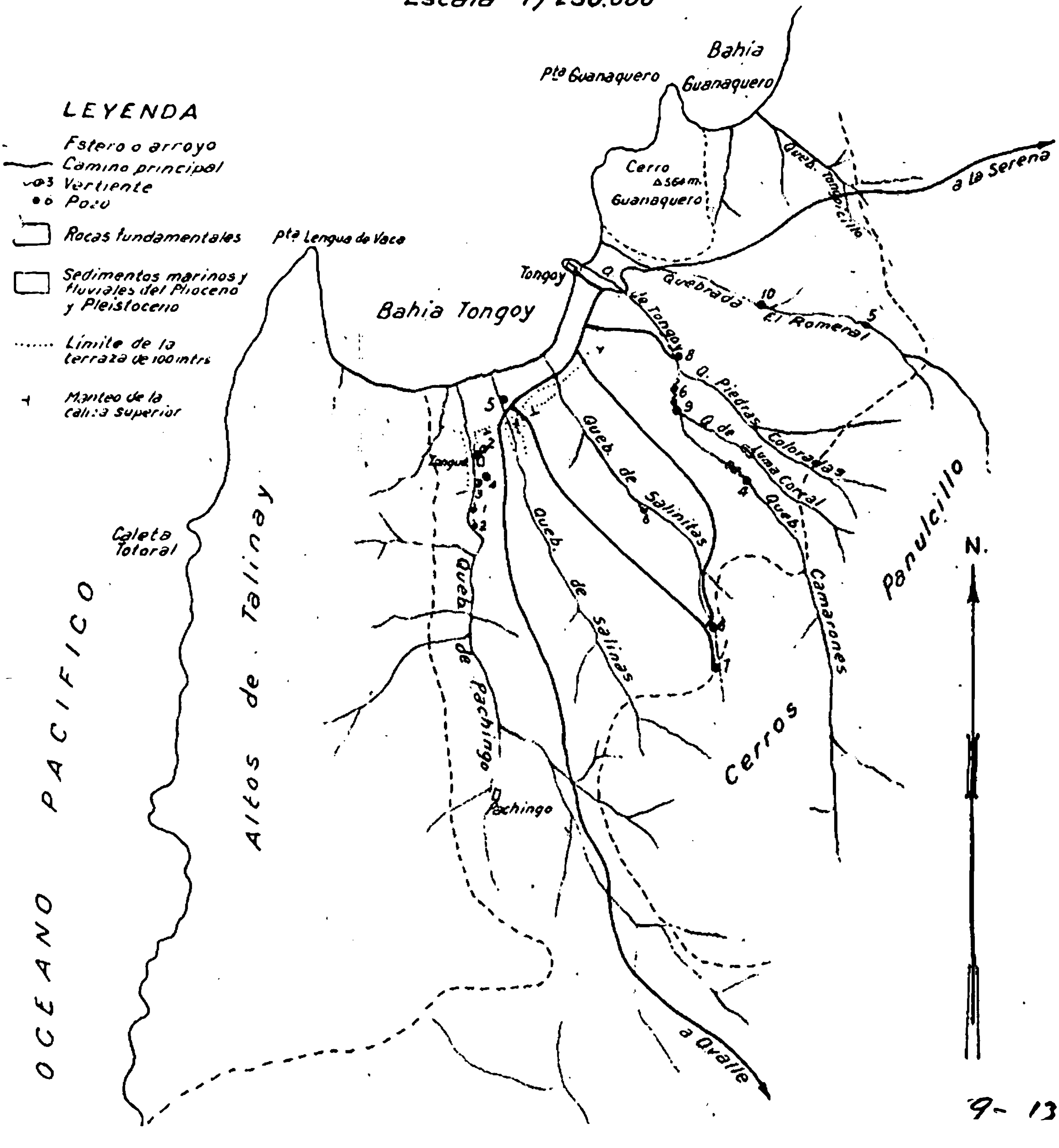
Croquis Nº 3 mostrando la zona de Tongoy, pozos y vertientes tipicos y la geologia general
Escala 1/250.000



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These rocks are considered to be of probable Pre-Cambrian age. The Panulcillo hills, Tongoy hill, and Guanaquero hill are formed of Cretaceous intrusive rocks - chiefly granite and granodiorite. The Cretaceous rocks probably also form the bedrock floor beneath the younger Pliocene and Pleistocene sediments of the plain of Tongoy. Near the seaward border of the 100-meter terrace between the Quebradas of Salinas and Salinitas, the Cretaceous rocks crop out in a low narrow ridge. They also appear in small outcrops where they have been exhumed by the downcutting of the Quebradas of Luma Corral and Camarones through the younger overlying sediments. (See sketch map No.3).

During early Pliocene time the plain of Tongoy was an extensive lowland at or very near sea level. At that time, the Rio Limarí followed a course across the lowland approximately parallel to the present position of the Quebrada of Pachingo and drained northward into Tongoy Bay. Apparently in this area the continental margin was slowly sinking during Pliocene time. In the subsiding lowland the Rio Limarí and other minor streams deposited a thick series of interbedded gravels, sands, and clays. Evidently the sea encroached from time to time and ~~occurred~~ during this same period because fossiliferous marine sands and clays are intercalated with the stream deposits. In the middle Pliocene most of Tongoy area sank below sea level. Apparently the sea entered the area from the north in a shallow embayment that extended to the base of the Panulcillo hills and as far south as Pachingo. In this embayment an extensive stratum of fossiliferous sandy limestone was laid down. This stratum ranges from less than a meter to several meters thick and forms the capping layer of the present plain of Tongoy.

In late Pliocene time the area of the embayment was lifted above sea level in a movement that tilted the recently deposited sediments gently to the north and west. Drainage to the north was then established on the emerged surface by the five principal quebradas of the area. During the late Pliocene uplift a minor stream cut back through the coastal barrier of the Altos of Talinay and diverted the Rio Limarí into the bedrock canyon that it now follows along the last 25 to 30 kilometers of its course. In Pleistocene time uplift of the area continued with brief pauses. During these pauses narrow marine terraces were cut by wave action near Tongoy Bay. At the same time the five quebradas cut down into the Pliocene sediments leaving narrow fluvial terraces corresponding to the marine terraces near Tongoy Bay.

In late Pleistocene time sea level rose slightly or the continental margin was depressed. As a result of this the five quebradas began to deposit sand and gravel in their lower courses. Apparently this cycle of deposition continues to the present.

The Pliocene sediments that underlie most of the Tongoy plain include semi-consolidated, stream gravel, sand, and clay in lenticular beds. These sediments are intercalated with fossiliferous marine sands and clays. Beneath the plain of Tongoy the Pliocene deposits have an exposed thickness of 100 meters, and it is probable that the maximum thickness may be much greater. A typical section of the Pliocene deposits measured by the writer about 2½ km. upstream from the mouth of the Quebrada of Salinas is as follows:

BASE OF SECTION AT STREAM CHANNEL

	Stratum	Thickness (meters)
(1)	Sand - fine, clayey, with stringers of pebble gravel, fluvial (?).	28
(2)	Sandstone - marine (?), semi-consolidated with occasional thin fossil horizons and stringers of gravel.	11
(3)	Gravel - Stream, pebbles up to 10 cm. in diameter, with stringers of fine to coarse unconsolidated sand.	18
(4)	Sandstone - fine-grained, semi-consolidated, with thin stringers of clay.	2
(5)	Gravel - semi-consolidated, with coarse sand. Pebbles up to 10 cm. in diameter of quartz, granite, and porphyrite.	5
(6)	Sand - fine-grained, unconsolidated, light-gray color.	1
(7)	Clay - sandy, white	1½
(8)	Sandstone - limy, semi-consolidated, light-brown color, some fossils.	2
(9)	Limestone - sandy; abundantly fossiliferous with numerous species of clams, oysters, and gastropods.	2
	Total thickness	70½ m.

Top of section at level of 100-meter terrace .

All of the members described in the above section have extremely variable thickness and may thicken or dove-tail out along the strike within distances of a few tens of meters.

The late Pleistocene and Recent sediments include the unconsolidated sand and gravel in the lower courses of the larger quebradas and the shore deposits of the lowest terrace near Tongoy Bay. They have relatively limited extension in the Tongoy area.

GROUND-WATER FEATURES:

The ground water in the rocks of the Tongoy area originates from the infiltration of rainfall. The average annual precipitation in the Tongoy area is of the order of 200 mm. Practically all of this occurs during the winter months, that is, from May to September. The infiltration from rainfall is probably greater and surface run-off is probably less in the Tongoy area than is the average in other parts of the province. This condition is due to the low gradients of the land surface and to the higher absorptive capacity of the Pliocene and Pleistocene sediments.

The water that seeps underground moves down to the zone of saturation whose upper limit is marked by the water table. A zone of saturation probably occurs in the Pliocene and Pleistocene sediments beneath most of the plain of Tongoy. The water in the zone of saturation moves northward and westward following the slope of the water table and the structural dip of the Pliocene sediments. This water discharges in springs along the lower courses of the five principal quebradas or in submarine springs beneath Tongoy Bay.

In the Tongoy area the depth to the water table is least along the channels of the large quebradas and greatest beneath the broad, undissected, interstream areas. Along most of the channel of the Quebrada of Pachingo, the water table is within a few meters of the surface. The water table is probably generally less than 20 meters deep along the upper and middle course of the Quebrada of Salinas, and less than 5 meters deep in the lower course, near Tongoy Bay.

In well No.7 near the head of the Quebrada of Salinitas the water table is at a depth of about 3½ meters, but somewhat farther downstream in well No.6 it is about 16 meters below the surface. It is probable that along the middle and lower stretches of this quebrada, the depth to the water table may range from 15 to 25 meters. Extensive meadows, where the water table is within a few meters of the surface, occur in the Quebrada of Tongoy and in the lower course of its principal tributary, the Quebrada of Camarones. In the Quebrada of El Romeral the water table is apparently at considerable depth, along the middle stretch. Well No.10 failed to encounter water at a depth of 30 meters.

Beneath the broad flats that lie between the quebradas and between the 100- and 200-meter contour lines, it is probable that the water table lies at depths of the order of 70 to 120 meters. Because of the geologic conditions of the area, it is unlikely that the water-bearing beds would be under artesian pressures of more than a few meters.

The Pliocene sediments are somewhat heterogeneous and therefore vary considerably in their water-bearing properties. The marine and fluvial clays, silts, and fine sands have low permeability. On the other hand, the intercalated beds of sand and gravel have moderate or even high permeability. These beds are generally saturated below the water table.

The Pleistocene stream deposits of the larger quebradas are composed principally of sand and gravel of moderate to high permeability. However, they are relatively thin. Where the water table is more than a few meters below the surface, these deposits may be unsaturated.

The ground water that occurs in the Pliocene and Pleistocene sediments of the Tongoy area has been extensively developed for domestic and stock use by dug wells. Data on most of the existing wells in the area are shown in Table 2. They are dug to depths ranging from 2.30 to 30 meters and are generally equipped with windmills. All of these wells are located in the quebradas. Apparently no attempts have been made to put down wells on the broad flats between the quebradas, probably because it was anticipated

TABLE 2.

DATA ON TYPICAL WELLS IN THE TONGOY AREA.

October 29-31, 1946.

Well No.	Name of owner or locality	Depth (meters)	Depth to water level (meters)	REMARKS
1	El Tangue	10.30	9.80	Windmill. Domestic use. Water from lenses of sand in Pliocene marine clay and silt. Located on low fluvial terrace of Quebrada of Pachingo.
2	" "	8.10	6.30	" " " " " 50 meters from well No. 1.
3	" "	9.80	9.30	Windmill. Stock use. Taps water in lenses of sand in Pliocene marine clay and silt. On same fluvial terrace as wells Nos. 1 and 2. At sheep corral.
4	" "	12.40	12.20	" " " " " 50 m. up slope from well No. 3.
5	In Q.of Salinas	3.50	2.30	Windmill. Stock use. Taps water in Pleistocene alluvial sand on floor of Q. de Salinas.
6	In Q. of Salinitas	15.90	Dry	Windmill. Stock use. Went dry for first time in Sept.1946. Taps water in Pliocene stream gravels.
7	In headwaters of Q. of Salinitas	4.20	3.20	Windmill. Stock use. Taps water in disintegrated Cretaceous granite.
8	In Q. of Tongoy	9.80	9.00	Windmill. Domestic and stock use. Taps water in Pliocene marine sand. Located on low fluvial terrace of Quebrada of Tongoy.
9	" "	2.30	1.40	Stock use. Taps water in Pleistocene fluvial sand and gravel.
10	In Q.El Romeral	30	Dry	Dug to a depth of 30 m. but did not encounter water.

TABLE 3.

DATA ON TYPICAL SPRINGS IN THE TONGOY AREA

October 29-31, 1946.

Spring No.	Name of owner or locality	Flow (in Lts./sec.)	Water-bearing material	Geologic horizon	REMARKS
1	El Tangue	0.05	Soft sand	Pliocene	Emerges from base of stream terrace Developed by shor trench. Stock use
2	" "	0.10	Sand with gravel	"	Emerges about 2 m. above base of stream terrace. Spring head dug out. Stock use.
3	In Q. of Salinitas	0.05	Gravel	"	Emerges on E. sid of quebrada, 10 m above flood channel. Unimproved. Stock use.
4	In Q. of Camarones	10 ±	Gravel	Pleistocene	Emerges from Plei tocene stream gra vels just upstrea from narrows in Cretaceous granit
5	In Q. El Romeral		Sand and gravel	"	Outcrops of water table in headwaters of Quebrad El Romeral.
6	In Q. of Tongoy	0.05 - 0.10	Sand and gravel	"	Small seeps and springs along flo of quebrada. Form extensive meadows and occasional marshy tracts.

that the water table would lie at considerable depth. Small springs that occur in the quebradas have also been developed for stock use. Data on some of the more typical springs in the area are given in Table 3.

Ground water has not been developed for irrigation to any important extent in the area. In the Quebrada of Pachingo, small extensions of eucalyptus trees and alfalfa are irrigated by gravity from shallow drains cut in saturated sand and gravel of the Pleistocene. In the Quebradas of Salinas and Tongoy are other small plots of alfalfa, eucalyptus, and poplars irrigated in a smilar manner.

CONCLUSIONS AND RECOMMENDATIONS:

In the flats lying between the large quebradas and between the 100- and 200- meter contours, it is probable that the water table lies at a depth of the order of 70 to 120 meters. In order to tap one or more productive water-bearing beds, it might be necessary to drill to depths of 10 to 20 meters below the water table. The pumping lifts in wells drilled in these areas are also likely to be of the order of 70 to 120 meters or more. Pumping from such depths is hardly within economic limits in the region. Because of these factors, the flats lying between the quebradas are not recommended for test drilling with a view to developing water from wells for irrigation.

Conditions for test drilling are much more favorable in the large quebradas. Along the Quebrada of Pachingo between Pachingo and Tangue, water for irrigation could be developed from wells of relatively shallow depth. Wells drilled to depths of 25 to 30 meters in this stretch should encounter one or more water-bearing horizons yielding of the order of 10 to 20 lts./sec. with pump. Wells of similar depth and yield could be anticipated in the Quebrada of Tongoy in the stretch between wells Nos. 8 and 9. (See sketch map No.3).

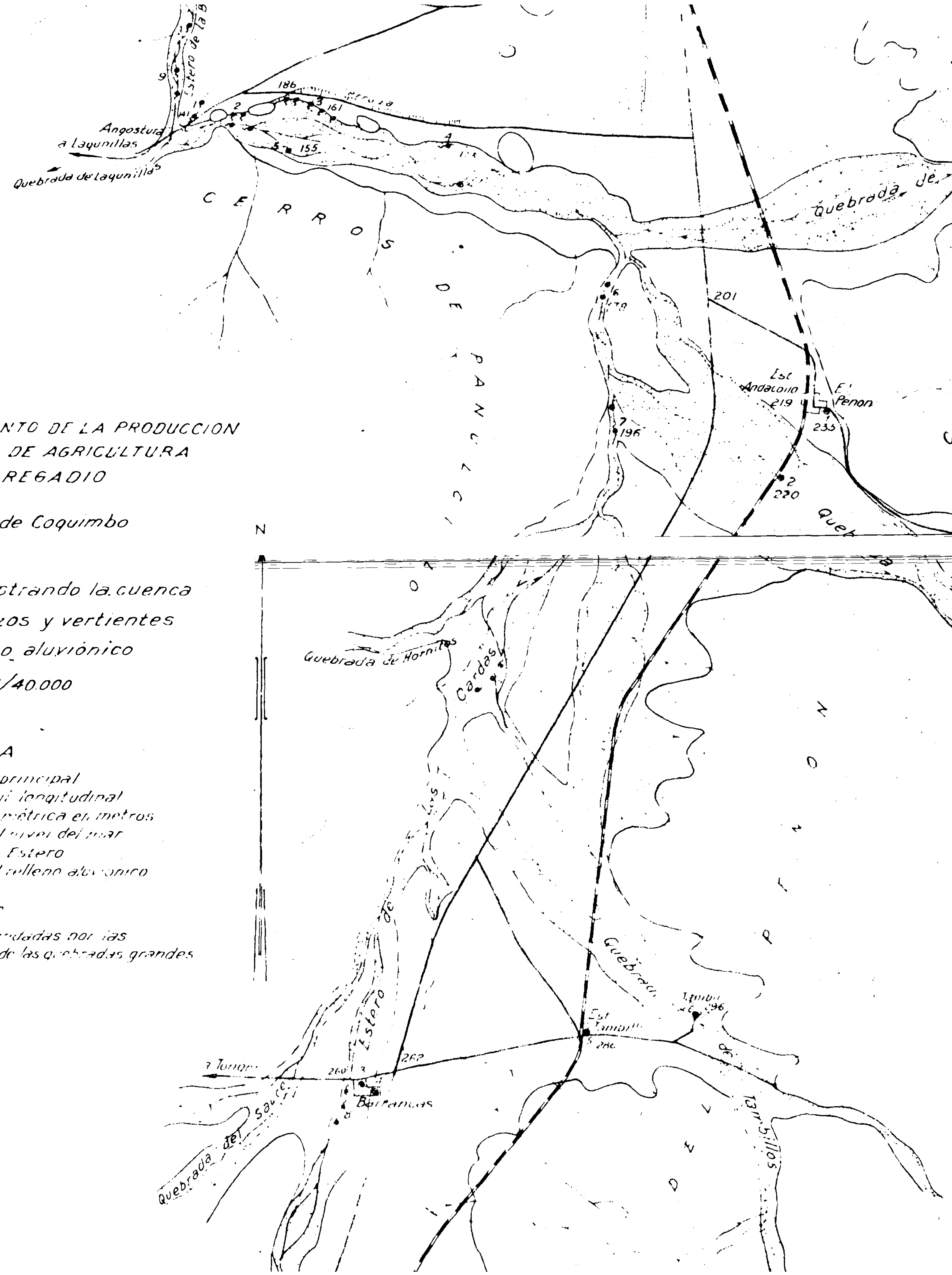
In the Quebradas of Salinas and Salinitas wells of the order of 35 to 45 meters deep may be required to tap productive water-bearing beds yielding 10 to 20 lts./sec. by pumping.

The water-bearing horisons in the Tongoy area are likely to be encountered principally in sand with or without gravel, hence provision should be made for well screens and for proper development of wells by surging and backwashing.

LAGUNILLAS VALLEY

TOPOGRAPHIC AND HYDROGRAPHIC FEATURES:

The Lagunillas valley extends northward from Las Cardas pass to a broad alluvial divide about 5 kilometers north of El Peñon and some 20 kilometers south of La Serena. The valley is some 18 to 20 kilometers long and from 2 to 5 kilometers wide, (See sketch map No.4). To the east of the valley are the El Peñon hills that reach elevations ranging from 1,200 to 1,500 meters, and to the west are the Pamulcillo hills which range from about 500 to 800 meters above sea level. The valley bottom slopes



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Quebrada del Sauce
a Tongoy
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260
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161
155

northward from an elevation of about 400 meters near the village of Las Cardas to some 200 meters along the alluvial divide at the north end. The valley has a pronounced assymetric cross profile with the lowest axis to the west along the base of the Panulcillo hills.

The principal stream of the valley is the Estero of Las Cardas. This stream rises on the Las Cardas divide and follows a course north along the eastern base of the Panulcillo hills. Near Angostura this stream joins the Estero of La Burra to form the Estero of Lagunillas. The latter drains west in a canyon cut through the Pamulcillo hills to enter the Pacific ocean in Guanaquero Bay.

The principal tributaries of the Estero of Las Cardas are the Quebradas of Martinez, Manzano, and Tambillos. These tributaries rise in the El Peñon hills. They enter the Lagunillas valley on broad alluvial fans that extend completely across the valley and have forced the Estero of Las Cardas to follow a course next to the border of the Panulcillo hills. The tributaries that enter the Estero of Las Cardas from the west are of relatively minor importance. The most important of these, that rise in the Panulcillo hills, are the Quebradas of Hornitos, El Sauce, and Carico. (See sketch map No.4)

In their upper courses the principal tributaries of the Estero of Las Cardas have small permanent flows of a few liters per second fed by perennial springs. In their middle and lower courses these streams are ephemeral, that is, they carry only the run-off of winter rains.

The Estero of Las Cardas is an intermittent stream in its middle and lower course. Characteristically in the dry season, it has short spring-fed stretches of a few liters per second separated by dry stretches. During the winter rainy season, it may carry flood flows of several cubic meters per second.

The Estero of Lagunillas has a perennial flow sustained by springs that rise near the junction of the Esteros of Las Cardas and La Burra. According to an approximate measurement made on October 10, 1947, the flow of the estero some 3 kilometers downstream from Angostura was 87 lts./sec. On the same day the flow of the Estero of La Burra at its mouth was 22 lts./sec. These measurements represent the base or ground-water flow at the beginning of the dry season. Toward the end of the dry season in May these flows would doubtless be somewhat less. From year to year the base flow of the Estero of Lagunillas may vary perhaps 20% due to excesses or deficiencies of rainfall in the catchment area of the springs.

GEOLOGIC FEATURES:

The oldest rocks in the area belong to the "Formación Porfirítica" of probably upper Jurassic and lower Cretaceous age. In the vicinity of the Lagunillas valley, these rocks include principally dark gray porphyrite lava flows interbedded with indurated tuffs and breccias. These rocks appear principally in the El Peñon hills from the Quebrada of Manzano south to Las Cardas pass. They also appear near the Angostura and in the Panulcillo hills opposite El Peñon. Cross-cutting the "Formación Porfirítica", are intrusive masses of diorite and granodiorite of probable upper Cretaceous age. These rocks occur in the Panulcillo hills between the Estero of Lagunillas and Las Cardas pass.

In middle Tertiary time the Jurassic and Cretaceous rocks were broken by faulting, and a north-south tectonic depression was formed along the site of the present Lagunillas valley. The most important structural movements probably occurred on the major fault that follows the western base of the El Peñon hills and the eastern side of Lagunillas valley. In these movements the rocks of the "Formación Porfirítica" in the El Peñon hills were tilted to the east at angles of 10 to 20 degrees. The surficial drainage of this depression was first established northward to Coquimbo Bay.

During early Pliocene time the Lagunillas depression and its northward extension to Coquimbo Bay lay near sea level. Apparently at this time the continental margin was slowly subsiding. In the sinking lowland the streams draining from the bordering higlands deposited their loads of clay, sand, and gravel. Within a few kilometers of the present shore of Coquimbo Bay, the fluvial sediments are intercalated with fossiliferous marine clays and sands. This condition suggests that slight oscillations of sea level must have occurred during this time. However, these is little evidence that the sea extended inland more than a few kilometers from the present shore of Coquimbo Bay.

The Lagunillas valley and the adjacent area to the north were lifted to considerable elevation above sea level in late Pliocene time. In response to the new base level, the Estero of Los Patos downcut its channel near Coquimbo Bay but the headward (to the south) migration of the downcutting was impeded by buried bedrock spurs that lay in the course of the stream. At the same time the Quebrada of Martinez build up the external border of its alluvial fan to the level of a low drainage divide through the Panulcillo hills.

In Pleistocene time uplift of the area continued with brief pauses. The Estero of Lagunillas draining west from the drainage divide in the Panulcillo hills cut headward and captured the drainage of the Quebrada of Martinez. As the uplift continued in the Pleistocene, the Estero of Lagunillas cut down into the alluvial fan of the Quebrada of Martinez, and extending itself headward by erosion in the alluvial fill, captured the drainage of the Estero of La Burra and then that of the Estero of Las Cardas. During pauses in the uplift narrow fluvial terraces were cut along the Estero of Las Cardas especially in the vicinity of the Angostura.

In late Pleistocene time sea level rose slightly or the continental margin was depressed. As a result the Estero of Lagunillas began to fill its lower course, to the west of the Panulcillo hills, with sand and gravel. This process continues to the present. However, the zone of alluviation in the lower course of the stream extends only to the western base of the Panulcillo hills. Upstream from that limit, the Estero of Lagunillas is cutting down in bedrock.

In late Pleistocene and Recent time the upbuilding of the interlocking alluvial fans of the Quebrada of Martinez, Manzano, and Tambillos, begun in late Pliocene time, continued, and the drainage of the Estero of Las Cardas was established in its present position.

In the Lagunillas valley the Pliocene sediments are largely buried beneath a cover of younger Pleistocene and Recent deposits. Moreover, it is doubtful if any of the existing wells of the valley end in sediments of the Pliocene. In all probability the Pliocene deposits have similar character to those of the Pleistocene although they are probably somewhat more indurated.

Practically all of the Lagunillas valley lying between the bordering highlands of older rocks is underlain by unconsolidated, stream-laid deposits of the Pleistocene and Recent. In the alluvial fans of the principal quebradas these deposits include poorly sorted sub-angular boulder, cobble, and pebble gravel with sand and some interstitial silt. The rocks types that appear in the gravel are chiefly porphyrite with some granite. Along the Estero of Las Cardas the stream deposits are somewhat cleaner and better sorted due to re-working by the stream.

GROUND-WATER FEATURES:

The ground water in the Lagunillas valley originates entirely from the precipitation on its drainage basin. On the higher parts of the El Peñon hills the average annual precipitation may reach 250 mm., but in the lower parts of the Lagunillas valley it may be of the order of 150 to 200 mm.

Practically all of the annual precipitation occurs in rains during the months of May to September. A part of this precipitation runs off on the surface in floods, but a part seeps underground either by direct penetration or by infiltration from floods in the stream channels.

The Jurassic and Cretaceous rocks of the El Peñon and Panulcillo hills have relatively small capacity to absorb and retain water in important quantity. For this reason most of the water that falls in these hilly areas runs off on the surface to the Lagunillas valley where it may seep underground in the permeable Pleistocene and Recent deposits of the large alluvial fans.

In spite of their relatively low permeability the Jurassic and Cretaceous rocks give rise to small but permanent springs in the headwaters of tributaries of the Estero of Las Cardas. Such springs in the Quebradas of Manzano and Tambillos commonly rise from tabular partings in porphyrite beds of the "Formación Porfirítica". In the aggregate the discharge of these springs is only a few liters per second that forms the dry-season flow in the upper courses of these quebradas. The Panulcillo hills are formed chiefly of upper Cretaceous diorite and granodiorite. These rocks when fresh and unweathered have low permeability. However, near the surface the fresh rock is often covered by a thin mantle of disintegrated rock known as arkose or "maicillo." This material has moderate permeability and capacity to store and yeld water in small quantities to wells and springs. In the Quebrada of El Sauce and Hornitos are several small springs that rise from "maicillo". The total discharge of these springs probably amounts to only a few liters per second.

The unconsolidated deposits of gravel and sand that form the Pleistocene and Recent alluvial fill of the Lagunillas valley have moderate to high permeability. In the lower part of these deposits is a zone of saturation sustained by infiltration either directly from rainfall or indirectly from the surface floods of the large quebradas.

The upper limit of the zone of saturation is the water table. In the Lagunillas valley the water table slopes westward from the base of the El Peñon hills and northward from Las Cardas to the Angostura. Water in the zone of saturation moves down the slope of the water table and discharges at the surface in springs along the Esteros of Las Cardas and La Burra. Data on the most typical of these springs are given in Table 5.

TABLE 4.

DATA ON TYPICAL WELLS IN THE LAGUNILLAS BASIN.

November 1-2, 1946.

Well No.	Name of owner or locality	Depth (meters)	Depth to water level (meters)	REMARKS
1	El Peñon	50.00	44.20	Windmill. Domestic use. Taps water in coarse, angular gravel. On alluvial fan of Q. of Manzano.
2	On Longitudinal railroad. 800 m. S. of El Peñon	35.30	26.50	Windmill. Domestic use. Irrigates small orchard. Taps water in cobble and boulder gravel of Q. of Manzano.
3	In village of Barrancas	4.80	3.50	Bucket and windlass. Domestic use. Taps water in poorly sorted gravel and sand.
4	About 500 m.S. of village of Barrancas	4.00	3.50	" " "
5	Estación Tambillos	27.70	19.70	Windmill. Railroad use. Taps coarse gravel and sand of Q. of Tambillos. Water level has lowered about 2 m. since a year ago.
6	In village of Tambillos	4.70	3.30	Bucket and windlass. Domestic use. Taps water in coarse gravel.
7		2.80	2.30	Bucket and windlass. Domestic use. Dug in poorly sorted gravel, sand, and silt.
8	Near village of Las Cardas	5.00	2.00	Taps water in cobble gravel.

TABLE 5.

DATA ON TYPICAL SPRINGS IN THE LAGUNILLAS BASIN.

November 1-2, 1946.

Spring No.	Name of owner or locality	Flow (lts./sec.)	Water-bearing material	REMARKS
1	Near Angostura	2	Coarse gravel	Rises in small gulch just upstream from junction of Estero La Burra and Estero Lagunillas.
2	" "	15-25	Coarse gravel and sand	Several small spring heads on line about 200 m. long between two bedrock nubbins. Contact or gravity springs.
3	" "	5-10	"	Several springs and general seepage on line about 50 m.long. Contact or gravity springs.
4	" "	1-2	Sand and gravel	Outcrop of water table in subsidiary channel of Estero of Las Cardas.
5	" "	"	"	" "
6	About 2 Km.SW. of El Peñon	0.5-1.0	"	Outcrop of water table in channel of Estero of Las Cardas. In "pothole". Water level fluctuates about one meter during year. Lowest in May.
7	About 2 Km. W. of El Peñon	"	Coarse cobble gravel and sand	In channel of Estero of Las Cardas. Natural well about 20 m. long and one meter deep.
8	Near Barrancas	5-10	Sand and gravel	Several small springs and general seepage in channel of Estero of Las Cardas. Diverted to irrigate several hectares.

The total ground-water overflow from the Lagunillas basin as measured in the bedrock channel of the Estero of Lagunillas ranges from about 80 to 110 liters per second during the dry season. A large part of this flow again seeps underground in permeable sediments beyond the western end of the bedrock canyon through the Panulcillo hills.

The water table is at the surface in springs along the Estero of Las Cardas, but in other parts of the alluvial valley of Lagunillas it may lie at depths of 45 meters or more below the surface. The depth to the water is suggested by the water levels in wells scattered over the valley. Typical examples are shown in Table 4.

The depth to water is least along the Estero of Las Cardas and greatest on the heads of the alluvial fans that emerge from El Peñon hills. However, the water-table in the channels of the large quebradas is at relatively shallow depth within the hill areas. Thus in the Quebrada of Tambillos the water level in well No. 6 is only 3.30 meters below the surface, but at well No. 5 at lower elevation on the alluvial fan the water level is 19.70 meters deep. (See Table 4).

The ground water in the Pleistocene and Recent deposits has been extensively developed for domestic and stock use by dug wells ranging from 2½ to 50 meters deep. (See Table 4). However, no large-scale attempt has apparently been made to pump water from wells for irrigation in the valley.

The springs that rise in the Esteros of Las Cardas and La Burra and in the headwaters of the large quebradas have been developed for the irrigation of tracts of a few hectares. The spring-fed flow of the Estero of Lagunillas is also partly used to irrigate lands near Guanaquero Bay.

CONCLUSIONS AND RECOMMENDATIONS:

The ground-water resources of the Lagunillas valley might be more effectively utilized in either of two ways.

(1) By constructing a dam with cut-off wall extending down to bedrock at the Angostura. In this manner it would be possible to store and regulate all of the ground-water overflow from the Lagunillas basin. At the same time it would also be possible to store and regulate such surface flood waters as might pass down the Estero of Las Cardas in the winter rainy season. The water stored in this manner could be delivered by gravity either through pipe line or canal or both to irrigate flat lands along the lower stretch of the Estero of Lagunillas and along the margin of Guanaquero Bay.

In the event this project is not feasible because of physical or economic conditions, irrigation from wells in the Lagunillas valley is possible.

(2) By wells located in the flats from 100 to 400 meters east of the Estero of Las Cardas and from Barrancas to the vicinity of the mouth of the flood-water channel of the Quebrada of Martinez. It is estimated that in this strip, the water table should be generally less than 20 meters below the surface. Moreover, from simple wells dug or drilled to depths of 30 to 40 meters, it should be possible to develop yields of 20 to 30 lts./sec. with pumps. The water-bearing zone should lie in coarse gravel, and hence sand screens should not be necessary in the saturated materials.

Under existing natural conditions considerable water is lost for beneficial use in the winter floods that pass down the Estero of Las Cardas. If the dam at the Angostura were not feasible, this water could be stored underground by artificial water spreading. In this manner the water table in the Lagunillas valley could be built up and the dry-season flow of the springs along the Estero of Las Cardas greatly increased.

Since the principal winter floods pass down the Quebradas of Martinez, Manzano, and Tambillos, it would probably be most feasible to practice water-spreading in the areas at the heads of the alluvial fans of these quebradas. In these areas the surface materials are very coarse gravels with high absorptive capacity. By diverting flood waters from the stream channels into prepared infiltration basins, considerable water could be delivered to the zone of saturation in these areas. The writer has already described in some detail in his report on the Azapa valley, one of the principal methods of water-spreading.

Artificial water spreading has been successfully practiced in California, U.S.A. for a number of years. It is used to build up the water table in those alluvial basins where it is naturally deep or where it has been artificially lowered by pumping. In the opinion of the writer the physical conditions in the Lagunillas valley are ideally appropriate for water spreading should economic conditions warrant in the future agricultural development of the area.

QUEBRADA OF LOS CHOROS

HYDROGRAPHIC AND TOPOGRAPHIC FEATURES:

The Quebrada of Los Choros drains an area of some 3,200 square kilometers in the northern extreme of the Province of Coquimbo. The headwater tributaries of the quebrada rise on the western slopes of a highland ridge formed by the Sierra del Condor, the Altos de Peralta, and the Cordillera de la Punilla. On the east this highland ridge is separated from the principal range of the Andes by the valley of the Rio del Carmen, the southern tributary of the Rio Huasco. This ridge in the Cordillera de la Punilla reaches elevations of well over 4,000 meters, but in the Sierra del Condor and the Altos de Peralta the elevations of the crest range from 3,000 to 3,500 meters.

As shown in sketch map No. 5 the principal headwater tributaries are the Quebrada of La Junta and Las Chacras. In these tributaries are small perennial streams fed by the run-off of winter rains and by springs and meltwater from snow during the dry season. Below Chignoles, the Quebrada of Los Choros is, for the most part, an ephemeral stream that carries only such surface run-off as may result from winter rains or melting snow in the spring. The water of average or minor floods commonly seeps into the channel gravels of the quebrada in its upper and middle course. Only rarely, when a major flood occurs, do surface waters pass down the quebrada to the sea. In the lower course of the quebrada near Trapiche, Choros Altos, the Angostura, and Choros Bajos are short perennial stretches fed by permanent springs. The surface flow in these stretches may amount to several tens of liters per second.

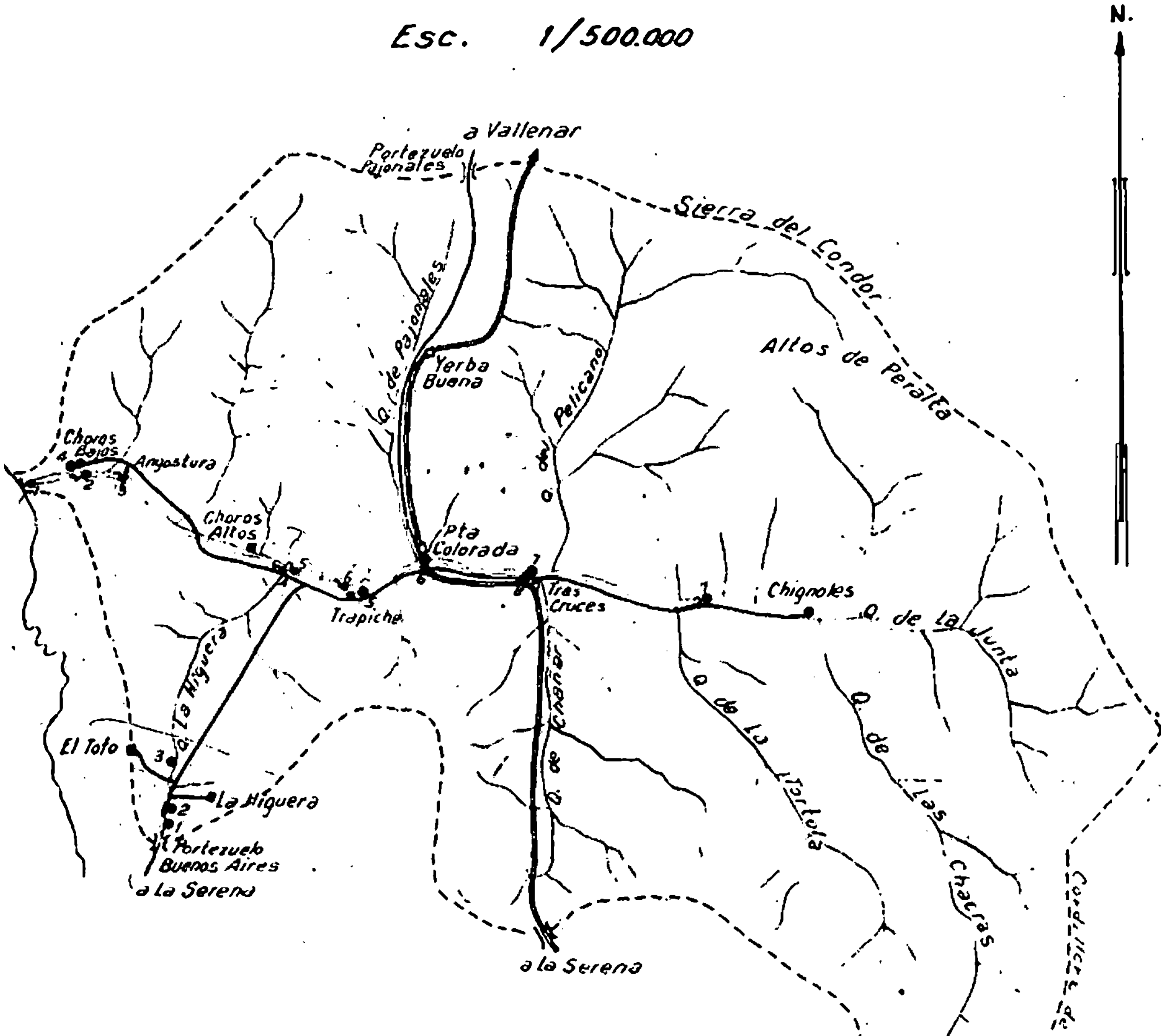
CORPORACION DE FOMENTO DE LA PRODUCCION
DEPARTAMENTO DE AGRICULTURA
SECCION REGADIO

ESTUDIOS AGUAS SUBTERRANEAS

Croquis Nº 5 mostrando la hoya hidrográfica de la Quebrada de Los Choros, pozos y vertientes tipicos.-

Provincia de Coquimbo

Esc. 1/500.000



LEYENDA

- - - - Limite de la hoya hidrográfica
4 ● Pozo
2 ✓● Vertiente
——— Camino Principal
═══ Ferrocarril Longitudinal

From Chignoles downstream to the sea the Quebrada of Los Choros follows an alluvial valley that ranges from about 200 to 1,200 meters wide. At the Angostura the alluvial valley passes through a bedrock constriction about 500 meters long and 70 to 90 meters wide. The average downstream gradient of the alluvial valley from Punta Colorada to the sea is about 1.4%.

GEOLOGIC FEATURES:

The Quebrada of Los Choros and its tributaries are cut in rocks of the "Formación Porfirítica" of upper Jurassic and lower Cretaceous age and in intrusive rocks of upper Cretaceous age. The Jurassic and Cretaceous rocks form all of that mountainous region within the drainage basin of the Quebrada of Los Choros. They also form the bedrock floors beneath the alluvial valleys of the quebrada and its principal tributaries.

The "Formación Porfirítica" is made up mostly of volcanic rocks - chiefly porphyrite lava flows interbedded with indurated tuff and breccia. Locally beds of marine limestone and shale are intercalated with the volcanic rocks. Cross-cutting the "Formación Porfirítica" are dikes and large intrusive masses of diorite and granodiorite with local differentiations of granite. These rocks, of probable upper Cretaceous age, appear extensively in the slopes of the quebrada from Trapiche downstream to the sea.

The drainage system of the Quebrada of Los Choros was probably established during early Tertiary time. In the middle Tertiary, the Jurassic and Cretaceous rocks of the region were broken by normal faults chiefly along north-south lines. One of the most prominent of the faults observed is that along the western side of the La Higuera-El Tofo valley. The Quebradas of Pajonales, Pelícano, and Chañar may also follow similar fault lines.

The Quebrada of Los Choros apparently maintained its course in spite of these fault movements, but some of its tributaries, as just described, adjusted their courses to the fault lines. By the end of Miocene time the stream draining the Quebrada of Los Choros had cut a valley in the Jurassic and Cretaceous rocks to a level considerably below the present stream channel.

In early Pliocene time the continental margin began to sink slowly. As a result, the lower course of the Quebrada of Los Choros was filled with silt, sand, and gravel eroded from its headwater areas. At the same time the La Higuera - El Tofo valley was filled with the alluvial deposits of the Quebrada of La Higuera and its tributaries. The alluviation that resulted from the sinking of the continental margin at this time probably extended some 25 kilometers inland from the present coast line or approximately to half way between Trapiche and Punta Colorada. At its maximum extent the alluvial fill attained a width of 2½ to 3 kilometers in the vicinity of Choros Altos. Here the exposed thickness of the Pliocene stream deposits above the present stream channel is some 50 to 60 meters. However, in the La Higuera-El Tofo valley at well No. 3 the deposits are 100 meters thick, and hence it is not unlikely that they may attain a corresponding thickness in the vicinity of Choros Altos.

During the early Pliocene submergence slight oscillations of sea level must have occurred. Because of these, fluvial sands and gravels are interbedded with fossiliferous marine sands, silts, and clay near Choros Bajos. At the time of maximum submergence the sea must have encroached inland

TABLE 6.

DATA ON TYPICAL WELLS IN THE BASIN OF QUEBRADA OF LOS CHOROS.

October 12-13, 1947.

Well No.	Name of owner or locality	Depth (meters)	Depth to water level (meters)	REMARKS
1	El Tofo	15.00	4.00	Potable water supply of El Tofo. Water in poorly sorted, consolidated βliocene alluvium Two wells 15 m. deep connected by infiltration trench 50 m. long and 4 m. deep. Captation yields average of 1,830 cu. meters per month with steam piston pump. Well located in Q. of La Higuera about 10 Km. from El Tofo.
2	El Tofo	4.00	2.00	Under construction. In Q. of La Higuera.
3	" "	100.00	10.00	Potable water supply of El Tofo. Water in poorly sorted, consolidated βliocene alluvium Saturated streaks between 10 and 21 m. Dry below that depth Well ends in bedrock. Well yields average of 1,090 cu. meters per month. In Q. of La Higuera 3 Km. E. of El Tofo.
4	In plaza of Choros Bajos	8.00	7.40	Bucket and windlass. On low terrace 2-3 m. above channel of Q. of Los Choros. Water in coarse cobble gravel and sand.
5	Trapiche	4.90	4.00	Windmill. In gravel and sand of Q. of Los Choros. Irrigates one hectare of olive and fig trees.
6	Pta.Colorada Municipal well	24.30	21.10	Bucket and windlass. Water in coarse gravel and sand of Q. of Los Choros. Excellent quality.
7	Tres Cruces Caja de Crédito Minero	17.00	16.80	Windmill. Water in coarse gravel and sand. Irrigates small plot of orange and lemon trees.
8	Tres Cruces Railroad sta.	24.00	17.40	Lift pump. Railroad use.

TABLE 7.

DATA ON TYPICAL SPRINGS IN THE BASIN OF

QUEBRADA OF LOS CHOROS.

October 12-13, 1947.

Spring No.	Name of locality	Flow (Lts./sec.)	Water-Bearing material	REMARKS
1	Near mouth of Quebrada of Los Choros	5-10	Pleist. and Recent sand and gravel	Flows into fresh-water lakes behind barrier beac Probably rises to surface on top of salt water.
2	At Choros Bajos	10-15	" "	General seepage in channe of Q. of Los Choros.
3	At Angostura	35-45	" "	At part of underflow of Q. of Los Choros. Forced to surface by constrictio of alluvial fill at bedrock narrows. Two natural spring heads developed by trenching. Irrigates land near Choros Bajos.
4	At mouth of Q. of La Higuera	5-8	Plio.,Pleist., and Recent sand and gravel	Rivulet formed by general seepage in the lower 150 m of the Q. of La Higuera. Evidently the ground-wate overflow from the La Higuera-El Tofo valley.
5	In Q. of Los Choros near mouth of Q. of La Higuera	50-60	Pleist. and Recent gravel and sand	Rises from general seepag in a secondary channel of Q. of Los Choros. Two principal spring heads. Water temperature 21°C. Excellent quality. Irrigates lands near Choros Altos.
6	Near Trapiche	30-40	" "	Rises from general seepag in a secondary channel of Q. of Los Choros. Several small spring heads that feed rivulet. Irrigates alfalfa, olive and ~~and~~ fig trees near Trapiche. Water temperature 23°C.
			" "	Outcrop of water table or natural well in depressio in channel of Q. of Los Choros.

as far as the Angostura. Apparently it cut an extensive terrace of marine abrasion in the rocky headlands and deposited fossiliferous sediments in the intervening depressions.

In the late Pliocene time the continental margin was uplifted. At the beginning of the uplift the channel of the Quebrada of Los Choros found itself near the south side of its alluvial valley at Angostura. As a consequence of the uplift, it cut down in its alluvial deposits but soon encountered a bedrock spur buried beneath a shallow cover of alluvium. It was thus forced to continue downcutting in bedrock rather than seeking out its old channel to the north.

In Pleistocene time uplift of the area continued with brief pauses. During these pauses narrow marine terraces were cut by wave action near the coast. At the same time above the Angostura corresponding fluvial terraces were cut from 5 to 35 meters above the present stream channel.

In late Pleistocene time sea level rose slightly or the continental margin was depressed. In response to this change in base level, the Quebrada of Los Choros began to fill its course with sand and gravel. This cycle of alluviation has evidently continued to the present.

The Pliocene sediments upstream from the Angostura are largely coarse fluvial gravel and sand with large amounts of interstitial silt and clay. In surface outcrop they are poorly sorted, semi-consolidated, and somewhat disintegrated by weathering. Near Choros Altos they have an exposed thickness of 50 to 60 meters in terrace bluffs but may attain a total thickness of the order of 100 meters in this vicinity. The highest terrace of Pliocene sediments ranges from 60 meters above the present stream channel near Choros Altos to some 5 to 10 meters near Trapiche. Near Choros Bajos the Pliocene fluvial deposits are intercalated with yellow and gray marine clays, silts, and sand with fossil-bearing horizons.

The Pleistocene and Recent stream deposits underlying the present alluvial valley form a strip ranging from 200 to 1,200 meters wide along the channel of the Quebrada of Los Choros. They extend from the vicinity of Chignoles downstream to the sea. These deposits are unconsolidated, sand relatively well-sorted cobble and pebble gravel and sand. Interstitial clay and silt does not appear to be abundant in the deposits. The rock types that occur in the gravels include porphyrite, granite, granodiorite, quartz, and occasionally limestone.

GROUND-WATER FEATURES:

As in most of the valleys of the province, the ground water in the Quebrada of Los Choros must originate almost entirely from the precipitation that falls on its drainage basin. Practically all of the annual precipitation in the basin occurs during the months of May to September. In the lower parts of the basin near the coast the average annual precipitation may be of the order of 100 to 150 mm., but in the highest parts of the basin it may exceed 300 mm. Below elevations of 2,500 meters precipitation occurs as rain, but at higher elevations snow falls are common during the cold months.

The rocks of the "Formación Porfirítica" and the Cretaceous intrusives have relatively small capacity to store or to yield ground water in important quantity. However, they sustain small springs that issue from tabular partings or from residual mantles of disintegrated rock.

The Pliocene sediments form the extensive terraces along the lower course of the Quebrada of Los Choros and the alluvial fill of the El Tofo-La Higuera valley. They consist of semi-consolidated and poorly sorted sand and gravel with large amounts of interstitial silt and clay. Because of these conditions, the deposits have low permeability and little capacity to store and to yield water to wells or springs. In the El Tofo - La Higuera valley wells Nos. 1, 2, and 3 obtain only meager supplies from thin saturated beds in these deposits. (See Table 6).

Because of their low permeability and relatively small absorptive capacity, most of the precipitation that falls in the upland areas of the Pliocene, Cretaceous, and Jurassic rocks runs off into the alluvial valley of the Quebrada of Los Choros. The Pleistocene and Recent deposits that underlie the alluvial valley are composed largely of unconsolidated gravel and sand of moderate to high permeability. In the lower part of these deposits is a zone of saturation whose upper limit is the water table. This saturated zone is sustained almost entirely by infiltration from surface waters that pass down the channel. Surface floods may result from winter rains or from the spring run-off of melting snow in the higher parts of the basin.

The water in the zone of saturation moves down the quebrada along the slope of the water table. It discharges at the surface in springs near Trapiche, Choros Altos, Angostura, and Choros Bajos. Data on the most typical of these springs are given in Table 7. At the Angostura is a bed-rock constriction which causes a part of the ground-water underflow of the quebrada to rise to the surface in springs. The flow of these springs on October 12, 1947 was approximately 45 liters/second. (See spring No. 3, Table 7.) Brüggen (x) in his manuscript report on the Quebrada of Los Choros suggests that the total underflow of the quebrada at this point might be of the order of 300 to 600 lts./sec. The writer would place his estimate on the lower side of this range. In any case accurate data as to the total thickness, width, and hydraulic gradient of the water table are needed to make a precise estimate of the amount of underflow through the Pleistocene and Recent alluvium at the Angostura. These data are not as yet available.

The depth to the water table in the Quebrada of Los Choros is suggested by the water levels in wells listed in Table 6. Between spring No.7 and Tres Cruces the depth to water in the channel of the quebrada may range between 5 and 20 meters. In the stretch from Tres Cruces to Punta Colorada it probably lies at depths of 10 to 20 meters. At Punta Colorada, the water table in the channel of the quebrada is about 11 meters below the surface; but to the north on the slope between the railroad station and the channel of the quebrada, the depth to water ranges between 11 and 25 meters.

From Punta Colorada downstream to the water table along the channel of the quebrada is generally less than 10 meters below the surface. In the vicinity of Trapiche, Choros Altos, Angostura, and Choros Bajos the water table rises to the surface in springs or lies within a few meters of the surface giving rise to flourishing growths of phreatophytes.

(x) Brüggen, Juan: Informe Geológico Sobre el Agua Subterránea de la Quebrada de Los Choros; p. 11, Santiago, November 19, 1942.

In the vicinity of Trapiche, Punta Colorada, and Tres Cruces water is pumped from wells by windmills for the irrigation of small orchards of olive, fig, orange, and lemon trees. The wells used for irrigation are dug to depths ranging from 5 to 30 meters. Apparently no attempts have been made to pump water for large scale irrigation in the quebrada.

Near Trapiche, Choros Altos, and Choros Bajos, the springs that rise in the channel of the quebrada are developed for the gravity irrigation of small tracts of corn, alfalfa, orchards, and garden truck.

CONCLUSIONS AND RECOMMENDATIONS:

There is a perennial and relatively abundant ground-water underflow that moves through the Pleistocene and Recent stream deposits of the Quebrada of Los Choros. This flow is partially utilized at present but could be more fully developed for irrigation. Some of the more evident possibilities are discussed below.

(1) By a low collecting dam with impermeable cut-off wall extending down to bedrock at the Angostura, it would be possible to irrigate extensive flat lands near Choros Bajos by gravity canals. Here it would be physically feasible to captate, store, and regulate all of the ground-water underflow of the Quebrada of Los Choros. The Pleistocene and Recent stream deposits at the Angostura are estimated to be generally less than 15 meters thick above bedrock. The minimum distance between the bedrock walls of the Angostura is some 70 to 80 meters. The impermeable cut-off wall necessary to captate the underflow would thus have to fit these dimensions. Moreover, a low surface dam would be necessary to store the water captured by the cut-off wall and to regulate the delivery of the water to irrigation canals.

Before a definite project is undertaken here, it would be desirable to dig or drill at least 4 test wells spaced at equal intervals across the Angostura. With these wells the precise depth to bedrock and thickness of the stream deposits could be ascertained. Moreover, by means of pumping tests on these wells it would be possible to obtain a close estimate of the amount of underflow through the Angostura. Surface floods pass the Angostura so infrequently that it would hardly seem economically feasible to construct a high dam for the purpose of retaining such flood waters for irrigation.

(2) Whether or not a ground-water captation is constructed at the Angostura, water for irrigation from wells could be developed in the vicinity of Trapiche, Punta Colorada, and Tres Cruces. At Trapiche are low terraces 5 to 10 meters above the stream channel that could be irrigated by short canals from wells located in the Pleistocene and Recent stream deposits of the alluvial valley. Here it is estimated that wells 10 to 20 meters deep should yield of the order of 15 to 25 lts./sec. with efficient pumping equipment.

At Punta Colorada is an extensive, cultivable flat lying between the railroad station and the main channel of the quebrada. In this area it is estimated that properly constructed wells from 20 to 40 meters deep should yield perhaps 15 to 30 lts./sec. Pumping lifts in this area may range from about 15 to 30 meters.

Near Tres Cruces, the Quebradas of Pelícano and Chañar join the Quebrada of Los Choros. In this zone are cultivable flat areas that could be irrigated from wells of the order of 25 to 35 meters deep. This zone has a frost-free climate that lends itself ideally to the cultivation of citrus.

In the Quebrada of Los Choros the water-bearing zone of the Pleistocene and Recent alluvium is generally in gravel and coarse sand. For this reason simple slotted casings in the water-bearing zone should suffice in wells constructed in these deposits. Moreover, natural gravel walls should form readily around the slotted casings after adequate surging and backwashing.

Santiago, Chile,
November 20, 1947.