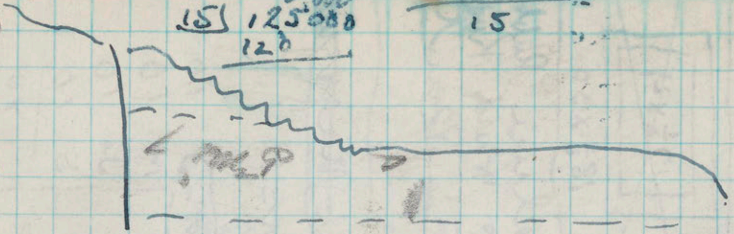
Oroya Water Supply

~~5112500.~~

15) 125000 (8000)
120

$\frac{500 \times 250}{15} =$



$\frac{2H}{15} = KW$

Lunellos Fraleig Clark Univ Britain

~~Dr Hopkins - 3 45 Fri 1/2~~

~~Frame~~
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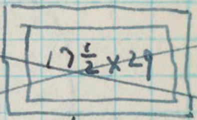
~~1/16~~



18½ x 30

Tourmaline Rubbers
Alloys Whisk Kodaks
~~Barber~~ Bank

Fuses

~~Hospital Magazines~~
~~Coupons~~

~~US Rubber~~ - J 10

Kuch	M	10
Bank	Je	10
Whisk	S	10
Rubbers		40
Kodak		

Pt 502

Agency No. 604 ORDER S № 44275

12/18

NAME Mr. Addicks

ADDRESS

PRINT EACH GLOSS DULL

ROLLS NO. EXPOSURES

FILM PACKS or PLATES SIZE

NEGATIVES print 5 (postcard size)

ENLARGEMENTS SIZE 5

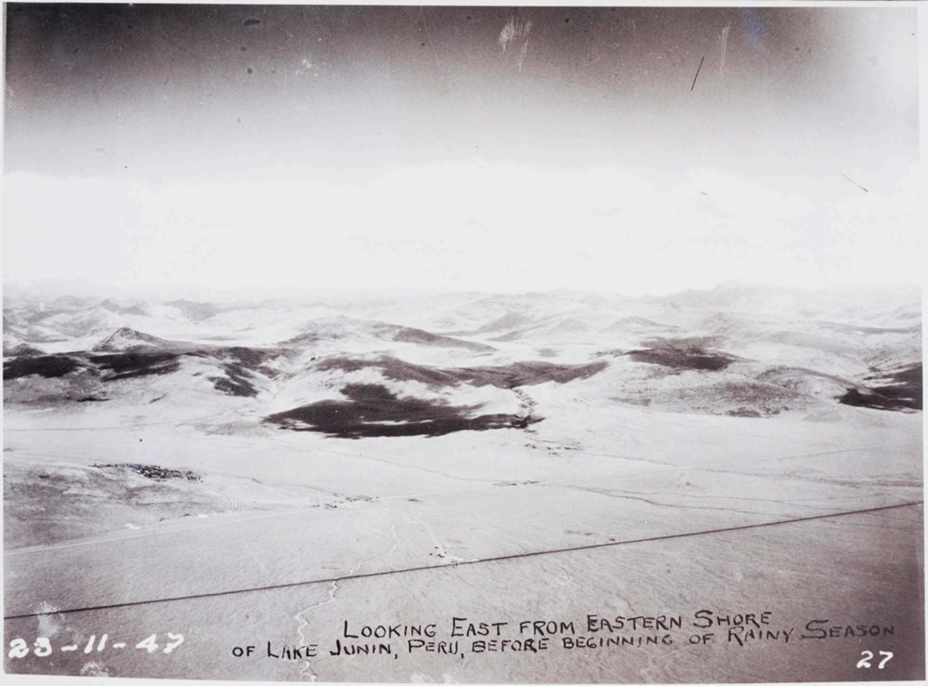
INSTRUCTIONS

Return all film and print

Copy 5

1.00
35

135


23-11-47
LOOKING EAST FROM EASTERN SHORE
OF LAKE JUNIN, PERU, BEFORE BEGINNING OF RAINY SEASON
27

DEC 23 1947

2.15 P – 11/4/47

~~50 mm~~ dia.

1/8" drop = 0.00102 cu. ins.
2" dia. = 3.14" area

~~3.14" x 0.001" = 0.00314 cu. in.~~

~~3.14" x 0.0003" = 0.000942~~

55 = 0.00018" thick

314000

0.00018
314000 | 55.0000
314000
236000

9 drops 0.0016" thick

~~Oil ring~~ – 3.14
2.00
1.14

~~oil 1/3 of 2/3 clear~~

1 drop			9 drops
4 – 1 day	– 4 grains diff	9K	11
8 – 2 "	12		20
18 – 3 "	30	13 <	33
15 – 4 "	45	27 –	60
		22 <	82
		21 <	103

1 sq mile = 27,878,400 sq ft.

8 x 15 = 120 sq. mi.

28 000 000
120
3360,000,000

thick 0.0001 ft. thick
84

336,000 cu. ft.

~~sp. gr. oil 0.8 or say~~
~~50# p. c. f.~~

~~16,800,000# lbs~~

x 7.5 = 2520,000 gal.

@ 10¢ = $252,000.

62.4# = 1 c.f.

62.4 x 3.14 / 144 = 1.36# beaker area 1' high

1.36 / 12 = 0.113# ditto 1" high

0.113 x 7000 = 791 grains 1" high

0.01" = about 8 grains

Naval Consulting Board
LAWRENCE ADDICKS, MEMBER
BEL AIR, MARYLAND

Official Business
Penalty for private use, $300.

Water
4 day loss
1/2 g + 22 gr.

219
22
241 gr. = 60 gr. p. day

241 / 791 = 0.3" loss

45 / 241 = 20%

6 days
1/2 g + 100 gr.
219
100
6 | 319 = 53 gr. a day loss

93 / 319 = 29%

20 drops oil = $2\frac{1}{2}$ gr.

1 drop = 0,125 gr.

1 drop oil = 0.000018 #

= 0,00029 cz.

1 c.i. H_2O = 0.036 #

1 drop oil = 0,0005 c.i.

plus 10% for sp. gr. = 0.00055 c.i.

18
16
108
18
288

1728 | 62.40 | .036
5184
10560

7 | 0.000018
0.000125

144 | 62.4 | .43
576
480
432

43 | 0.290 | .007
301

36 | 0.180 | 0.005
180

CERRO DE PASCO COPPER CORPORATION

40 WALL STREET, NEW YORK 5, N.Y.

Memorandum To: Mr. R. P. Koenig May 21, 1951.

From: B. C. Maine

Subject: Corporation Power Supply and Demand.

Expenditures currently being made for electric generating equipment have called for a statement of Corporation power policy. What is the trend of our power demand curve? What has been done and is being done to keep the power supply curve above it? Why install the 4th Malpaso unit? This memorandum aims to answer these questions.

D E F I N I T I O N S

Synchronized Network. System of generating plants and substations tied together electrically by transmission lines and switchgear, sometimes referred to hereafter as the "system".

Storage. Water accumulated during the rainy season and released to supplement uncontrolled run-off during the dry season.

Pondage. Water contiguous to a hydroelectric plant or plant intake maintained in sufficient volume to compensate for hourly and daily load fluctuations. Although its rate of expenditure is variable its rate of replacement is approximately constant.

Note: Storage is sometimes confused with pondage. Storage is relatively greater than pondage and is frequently, although not always, located far from the plant. Lake Junin is storage for Malpaso while Lake Malpaso is its pondage.

Acrefoot. Unit of water volume common in hydroelectric practice equal to one foot of water over an area of one acre. Therefore, 1 acrefoot = 43,560 cubic feet.

Cfs = Cubic feet per second.

Horsepower (of a waterfall) $= \frac{\text{(cfs) x (head in feet)}}{10}$.

The above formula is accurate enough for estimating purposes. It assumes a turbine efficiency of 88%, the average value occurring in practice. Since it is expressed in English units its simplicity is due to coincidence.

Power factor. Cosine of the electrical angle (Cos θ) by which instantaneous current leads or lags behind instantaneous voltage. Hence, Cos θ varies between 0 and 1.0.

1 Megavolt - ampere (mva) = 1,000,000 volt-amperes.
= 1,000 kva.

<u>1 Megawatt (mw)</u> = 1,000,000 watts.
= 1,000 kw.

<u>Mw = Mva (Cos θ).</u>

<u>Installed capacity</u>. The sum of the mva or mw rating of all installed generating units.

<u>Firm power</u>. Megawatts (mw) which the system can deliver continuously, regardless of season.

<u>Secondary power</u>. Megawatts which the system can deliver during the rainy season.

<u>Peak generating capacity</u>. Megawatts which the system can deliver for short periods to supply peak loads. It is a function of stream flow, pondage and installed capacity.

<u>Maximum demand</u>. Maximum total load in Megawatts which occurs on the system during a specified time interval. In this discussion the daily maximum demand is used.

<u>Average load</u>. Product obtained by dividing the megawatt-hour consumption during a given period by the number of hours in that period. In this discussion daily average load is used.

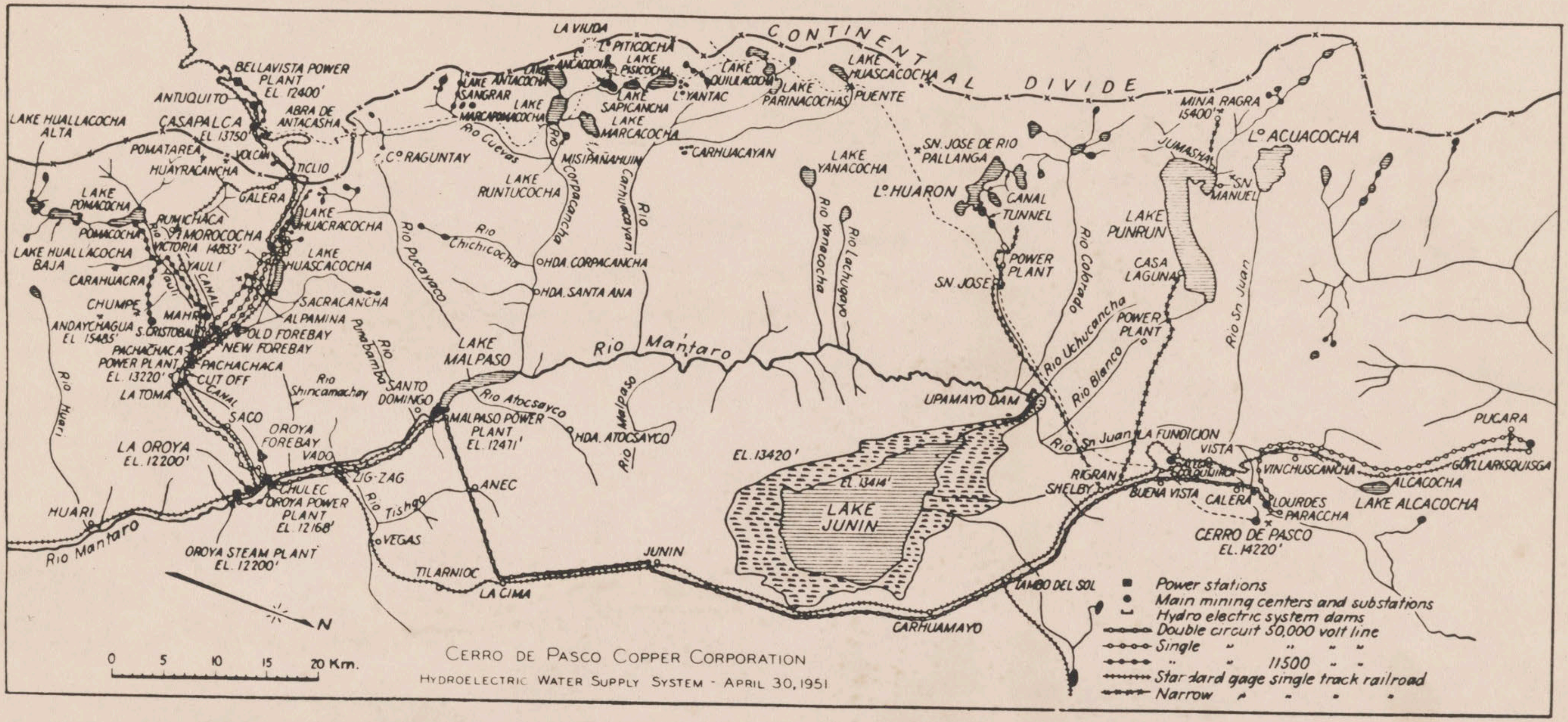
<u>Base load plant</u>. Power plant which generates at a constant rate depending on the rate at which water is received. A base load plant is operated "on the block", or with its turbine governors set in such a way that all the water is utilized with none rejected for governing purposes.

<u>Frequency regulating plant</u>. A power plant which regulates the frequency of the system. Such a plant has its machine governors set in such a way that the water admitted at any instant is proportional to the demand on the plant.

<u>Run-of-river plant</u>. A hydroelectric plant without storage of pondage. Inherently its capacity depends on the instantaneous value of stream flow at its intake.

<u>S Y S T E M G R O W T H</u>

Your attention is directed to the following chronological table of system growth, and to attached map of Hydroelectric Department water supply.



CERRO DE PASCO COPPER CORPORATION

HYDROELECTRIC WATER SUPPLY SYSTEM - APRIL 30, 1951

Name of Plant	Year Built or Acquired	CAPACITY		
		INSTALLED		FIRM
		MVA	MW	MW
Oroya	1914	11.25	9.0	9.0
Bellavista	1918	2.0	1.6	1.0
Pachachaca	1919	3.75	3.0	0.5
Oroya Steam Plant	1922	7.5	6.0	—
Pachachaca Extension	1927	11.25	9.0	6.0
Malpaso	1936	51.0	40.8	25.0
Present Total		86.75	69.4	41.5
Under Construction				
Malpaso water Increase	1951			7.0
Malpaso 4th Unit	1952	17.0	13.6	56.0
Paucartambo	1953	75.0	60.0	
Grand Total		178.75	143.0	104.5

DESCRIPTION OF INDIVIDUAL PLANTS

Oroya hydroelectric station is the only plant whose firm power equals its installed capacity. It is inherently a base load plant because it receives its water through a long canal. Its water supply is composed of the discharge from the Kingsmill Tunnel and tail water from the Pachachaca plant.

Bellavista plant was the sole source of power for the Casapalca mine when operated by Sociedad Minera Backus & Johnston. It is held in reserve as emergency power supply for the Casapalca mine in the event of an interruption in the system power supply. It cannot at present be synchronized with the 50-kv network because of its inadequate circuit breaker interrupting capacity, hand voltage control and transformer complications at Bellavista substation. Changes will be made to permit synchronization in the near future. Bellavista's contribution will be needed during the next two and a half years.

Pachachaca consists of two plants under one roof. The first was built with one 3.0-mw unit whose water supply comes from the Huacracocha - Huascacocha lake system near Morococha. Three duplicates of the first unit were installed eight years later with water supply from Rio Huallacocha. Inadequate storage of 10,000 acrefeet in Lakes Huallacocha Alta and Huallacocha Baja resulted in the creation in 1941 of 21,400 additional acrefeet of storage by damming Rio Huallacocha at Pomacocha. In 1934 Pachachaca lost 25% of its water supply through completion of the Kingsmill Tunnel. Water flowing from Morococha mine through the tunnel formerly was pumped into Lake Huascacocha feeding Pachachaca Unit No. 1. Pachachaca is operated as a base load plant.

The steam plant with its two 3.0-mw steam turbine generating units originally received steam from waste heat boilers interposed between reverberatory furnaces and stack. Because the steam thus generated is now mainly used for industrial processes there is a negligible energy contribution from this source. One of the units is kept spinning and synchronised with the 50-kv network to provide short-time emergency power for vital smelter operations during hydroelectric power failures in the smelter. Contingent on the completion of repairs the steam plant can deliver rated capacity when supplied with steam from auxiliary boilers.

Malpaso, supplied with 3 Francis turbines operating under 250 feet of head has 40,000 acrefeet of pondage and 412,000 acrefeet of storage, hence is ideal for frequency control. It will continue to exercise this function after the addition of new generating capacity to the system.

Note: For a full description of the Corporation's power system, see pages 563-566, November, 1945, issue of "Mining and Metallurgy".

ISOLATED HYDROELECTRIC PLANTS

Name of Plant	CAPACITY INSTALLED MVA	CAPACITY INSTALLED MW	FIRM MW
Pachacayo	0.4	0.32	0.32
Consac	0.1	0.1	0.05
Sunca	0.625	0.5	0.5
Siria	1.0	0.8	0.8
Raura	0.1	0.1	0.1
Huapa (leased)	1.2	1.0	1.0
Total	3.425	2.82	2.77
Atocsayco	Negligible		
Cochas	Negligible		

Pachacayo plant is power supply for the Pachacayo ganadera.

Consac plant is located at Consac ganadera.

Sunca plant was built on the Rio Huancachi to supply power for development of the Yauricocha mine.

Siria plant was built to supplement Sunca power for Yauricocha mine operation. It operates in synchronism with Sunca.

Raura plant was assembled from miscellaneous used parts as power supply for a 100-hp compressor at the Raura geological examination site. It is now in moth balls and will so remain until the Raura operation is revived or definitely abandoned.

Huapa station is located on the Rio Opamayo and supplies power to the leased Julcani operation. The two generating units are of good Swiss design but labor under the handicap of dirty water during the rainy season. Its sand trap is inadequate in size and has poor cleaning facilities.

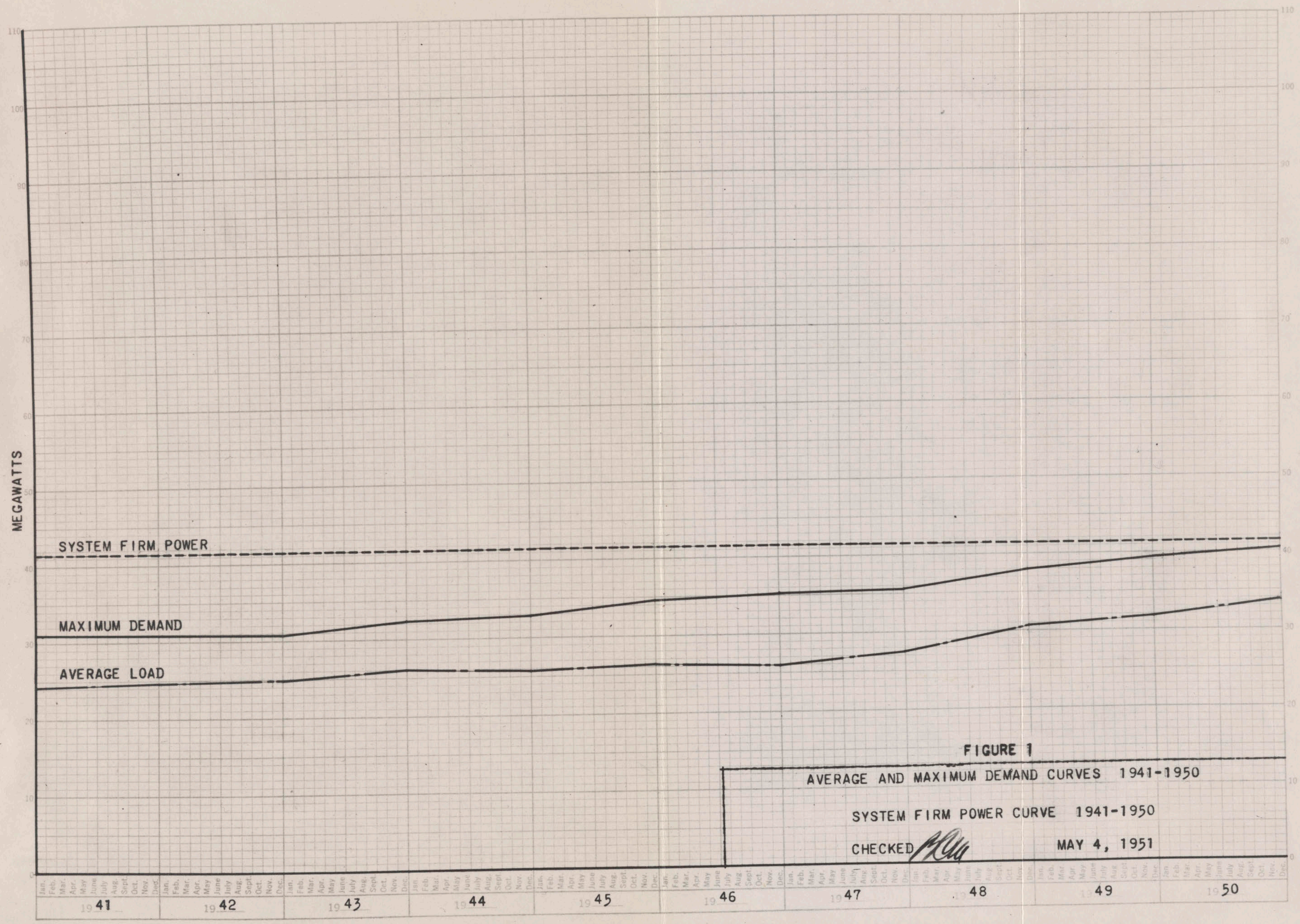


FIGURE 1

AVERAGE AND MAXIMUM DEMAND CURVES 1941-1950

SYSTEM FIRM POWER CURVE 1941-1950

LOAD TREND

Electric power use per unit of Corporation finished product is on the increase for several reasons.

1. Depletion of direct-smelting ores makes ore concentration increasingly necessary.

2. Pumping increases as mine operations go to progressively lower levels.

3. Electrolytic and electrothermic refining of metals are assuming new importance in Corporation operations.

4. Electric power sales to nearby custom ore shippers are being made in order to increase and stabilise smelter feed.

Increases in power use due to the above causes are specific in amount and predictable. There is also a tendency which is referred to as "creeping" growth. Unpredictable, this increase comes from numerous small installations such as residence lighting and heating, alterations in existing plants and load increases in custom ore shippers' operations. In the past, this creeping growth has amounted to an average annual increase of 1.57% of existing average load. This factor has been superimposed on specific future load increases occasioned by the construction of new plant units. It has been observed, also, that system maximum demand values have been 123% of the daily average.

Figure 1 attached, entitled "Average and Maximum Demand Curves 1941-1950" shows graphically how system average load, maximum demand and power supply have varied during the past ten years.

WATER EXAMINATIONS

The refining of zinc has long been on the Corporation agenda. Anticipation of substantial load increase has prompted the management, on various occasions, to sponsor the investigation of water power sites in the vicinity of Oroya.

The table below summarises the characteristics of the projects examined:

PROJECT	HEAD FEET	WATER CFS	FT. TUNNEL OR CANAL	POTENTIAL FIRM POWER - mw
Malpaso	250	1360	7,000'	25.0
Junin Tunnel	315	1080	30,000'	25.0 (seasonal)
Corpacancha	300	1270	52,000'	28.0
Malpaso-Oroya	200	1400	60,000'	20.5
Majorada	230	3000	33,000'	50.0
Carpapata	2,205	435	61,400'	60.0
Pachachaca - Oroya Increase				6.0
Ingahuasi	310	2050	Penstock only	45.0
Mantaro Bend	3000	3000	55,000'	600.0
Paucartambo	1600	510	39,500'	56.0

The Malpaso plant, now in service, is mentioned because its investigation was going on contemporaneously with several of the others listed. There was, as a matter of fact, sentiment in favor of its abandonment when diamond drill holes put down in Malpaso Canyon revealed that the distance to bed rock was disappointingly great. Sanderson and Porter, who conducted the examination, proposed a rock-fill dam resting on river gravel with a concrete apron and cut-off wall going down to bed rock. This design was adopted and proved to be sound.

Strategically, Malpaso fitted into the need of a plant in the system with adequate pondage for frequency control without wasting water.

Although Malpaso was built with the thought that it would later be used for zinc production, its use for that purpose has been largely circumvented by the creeping growth which has occurred during the postponement of the zinc program.

The Junin Tunnel project visualized tapping Lake Junin at its southern tip and conducting the water through a tunnel to the Mantaro River. Such action would permit drawing the lake down to a lower level than is now possible. In its favor may be said:

1. Lake Junin water records have been kept long enough to be reliable.

2. Lake Junin water is clean with no attendant abrasive problem.

3. No dam would be required.

Its disadvantages would be:

1. System firm power increase (25 mw) would be inadequate for the zinc program. Two plants of this capacity would have to be built.

2. Tunnelling conditions were reported by geologists to be unfavorable.

3. Extensive dredging operations through 3 kilometers of weeds would be required to get to deep lake. This objection was intangible when it was made, but subsequent dredging operations in the Upamayo channel have revealed that it is virtually impossible to remove these weeds.

4. The plant would be seasonal in operation, there being no possibility of generating power during the rainy season.

The Rumichaca project is not listed in the table because its subsequent investigation by the Hydro Department proved it to be impractical. For this plant a dam 70 feet high would have to be built near San Blas, backing water up to the toe of Upamayo Dam. From the crest of Rumichaca Dam water would be conducted through a canal to the powerhouse about 5 kilometers downstream.

When viewed on the Mantaro profile map, Rumichaca seemed to have merit due to the relatively steep gradient in the river in that area (0.9 percent with a 5 km canal). However, when surveyed, it was seen that Rumichaca plant could not be built at any cost for these reasons:

1. The only dam site is on a blocky, highly fractured volcanic intrusion which would be pervious under the pressure proposed.

2. The canal, if it were to terminate at the bank, would have to be built on a trestle.

3. The only possible solution would be to build a canal limited in length to one kilometer, resulting in a total head of only 130 feet which would limit the firm plant capacity to 10.0 mw.

The Corpacancha project would have a dam 60 feet high and a canal 15 km long terminating at a powerhouse located near the upper end of Lake Malpaso. In consideration of its estimated firm capacity of 28.0 mw it is easily the most attractive of the undeveloped sites on the Mantaro upstream from Oroya.

For the Malpaso-Oroya Canal scheme a canal 15 kilometers in length would begin at Malpaso tailwater and terminate in one of two alternative sites:

1. At Shincamachay where a minority group advocated that an electrolytic zinc plant be built.

2. At Oroya just across the river from Oroya hydroelectric station. Inherently high in cost per unit of output due to its low head, this plan seems to have little merit.

At Mejorada a hydroelectric plant would take advantage of a relatively steep gradient in the Mantaro between the villages of Izcuchaca and Mejorada. Water would flow through a tunnel 10 kilometers long to a plant with a firm capacity of 50.0 mw.

Carpapata or Tarma project.

On September 28, 1928, Mr. C. S. Williams, Superintendent of Power, submitted a preliminary report on a plant to harness the Palca, Huasahuasi and other streams tributary to the Rio Tarma downstream from the village of Tarma. His water measurements were made by current meter, and although he did not so state, he inferred that minimum flows given were without the benefit of storage. The following table summarizes his conclusions:

	POWERHOUSE NO. 1	POWERHOUSE NO. 2	POWERHOUSE NO. 3
Horsepower	45,000	68,500	87,100
Megawatts	31.5	48.0	60.0
Plant Elev.	6,470'	5,904'	5,904'
Static Head	1,550'	2,205'	2,205'
Cfs available			
Rio Santa Rosa	31.53	31.53	31.53
Rio Palca	128.89	128.89	128.89
Rio Huacuas	70.00	70.00	70.00
Rio Huasahuasi	89.53	89.53	89.53
Rio Malmalma		22.26	22.26
Rio Yanango			93.04
Total cfs	319.95	342.21	435.25
Total tunnels	30,450'	48,800'	61,400'
Est. Cost U.S.Cy.	$6,268,100	$9,334,100	$11,516,935

It is interesting to conjecture what Mr. Williams' cost estimates would have been in 1951.

Dated February 7, 1930, a covering letter signed by Mr. Harold Kingsmill accompanied an undated report by A. D. Bryant, whom many Cerro employees will remember as a civil engineer of marked ability. His findings overlap those of Mr. Williams, and are probably more accurate than the former because his water volumes are based on weir measurements. He further stated the exact amounts of storage required for each project. His results are summarized below:

PROJECT NO.	1	2	3	4	5
Water cfs	300	400	500	500	600
Head ft	1025	1350	1670	1930	1100
Horsepower	28,000	49,200	75,750	87,500	60,000
Ft. of tunnel	22,450	35,320	27,470	35,050	29,250
Penstock ft.	1,500	2,250	2,050	2,850	not stated
Storage acrefeet	22,490	23,320	21,640	21,640	17,590

Mr. Bryant listed a total of 23 small lakes which could be dammed to secure water storage of 30,137 acrefeet. He did not state how many lakes would be required for each project. He made no cost estimate.

Pachachaca - Oroya Increase.

It has been shown in recent Hydro Department reports that a system firm power increase of 6.0 mw could be realized from certain additions to the Pachachaca-Oroya water supply system.

1. Add 25,000 acrefeet of storage capacity at Lake Huallacocha Baja, to be accomplished by:

a. An increase of 45 feet in the height of Huallacacha earth dam, or,

b. Construction of a tunnel to secure greater drawdown of the lake.

2. Raise the walls of the Oroya canal about two feet.

3. Install a duplicate Saco syphon.

4. Install a duplicate Oroya penstock.

5. Install another 3.0 mw generating unit at Oroya hydroelectric generating station.

No detailed estimate of the cost of making these changes is available, but the consensus of $1,000,000 would bring the unit cost to $170 per kilowatt.

Ingahuasi.

Located on the Mantaro River at a point 29 kilometers downstream from Huancayo is a narrow gorge which could be dammed to give an effective head of 310 feet. A gaging station was established which in the dry season of 1950 indicated a minimum flow of 2,048 cfs. (Corrected for diversion of the Rio Colorado and assuming that the 500,000 acrefeet of storage made available at Lake Junin were to be all withdrawn during the dry season).

$$\text{Ingahuasi Hp} = \frac{2048 \times 310}{10} = 63,488$$

Converting this value to kilowatts and assuming a generator efficiency of 95%, 63,488 x .746 x .95 = 45,000 kw or 45 mw at the Ingahuasi busbars. Ingahuasi is located approximately 160 kilometers from Oroya.

Mantaro Bend or Pongor project.

Same distance downstream from Mejorada the Mantaro River makes a loop around a narrow strip of land known as the Tayacaja peninsula. If this peninsula were to be cut at the shortest section by a tunnel 16 kilometers in length, it would permit the construction of a power plant with a net head of 3,000 feet. Hence, $\text{Hp} = \frac{3000 \times 3000}{10} = 900,000$ Hp. (Assuming 3000 cfs).

Converted, this is equivalent to a firm power of approximately 600,000 kw or 600.0 mw. This potential capacity makes the Mantaro Bend one of the really great hydroelectric projects of the Western hemisphere. It is entirely feasible to build, having several good intake sites in the vicinity of Vigapata, with geologically approved tunnelling conditions. The dam would be only high enough to divert water to the tunnel. A sand trap would be required. It has been proposed that the high head be utilized in two equal steps but this suggestion would not necessarily be carried out because successful hydro plants with heads much greater than 3000 feet have already been built in Europe.

As scaled off on Corporation maps, the Mantaro Bend site is located 250 kilometers or about 150 miles from Oroya.

The economic voltage of transmission to Oroya would be of the order of 220 kilovolts. This voltage is believed to be technically attainable at the maximum elevation reached by the line, which would be at Oroya.

Paucartambo.

The site of this development, located downstream from the confluence of the Huachon and Paucartambo Rivers, was first visited by Corporation representatives in September, 1947. Because of the river's steep gradient and impressive flow the region appeared to have interesting possibilities. Photographs taken at that time stimulated interest among Corporation executives. In 1948 a stream gage was installed and a stadia survey of the stream's plan and profile was made from Tingo de Hualca to Machicurapata. A weir, built 1/2 kilometer below Tingo de Hualca, was finished in 1949. As a result, hydrographs of the stream are available for the years 1949 and 1950.

The feasibility of the Paucartambo development depends on two major premises:

1. That the Paucartambo plant be normally connected to the existing synchronized network to allow interchange of power between the old and new systems. Under that condition Lake Junin storage and Lake Malpaso pondage become available as compensation for fluctuations in Paucartambo's water supply.

2. That Malpaso's peak generating capacity be great enough to take care of new peaks imposed on it by Paucartambo.

Without Malpaso, Paucartambo's firm power drops to 40.0 megawatts. With Malpaso, including the Malpaso 4th unit, the system firm power is increased 56.0 megawatts and reaches a total of 104.5 megawatts.

Rancon.

The Hydroelectric Department was recently requested to prepare a preliminary report on hydroelectric power possibilities in the vicinity of Oyon near which is a deposit of coal whose characteristics are currently being investigated. The best location at hand is apparently the Rancon site, a high cataract on the Rio Oyon. A weir will be built there in the near future, or may already be in operation. As soon as an engineer is available, a survey will be made to determine the head and best powerhouse location. The site impresses the observer as being ideal for power development and appears to have potentialities considerably in excess of the 2.0 megawatt demand.

The cost of the Rancon plant will have to compete with the cost of building a transmission line into that district from the 50-kv network. A preliminary estimate indicates the isolated plant would be the cheaper of the two. Further, the isolated plant would add to our power resources, while the transmission line would be a drain on our present resources.

SYSTEM LOAD AND SUPPLY

Any plans for building new power facilities should naturally be prefaced by an analysis of expected load conditions. In July, 1950, a prediction of system load up to 1958 was made and results were incorporated in Hydro print No. J-27 entitled, "Average and Maximum Demand Curves 1940-1958 and Proposed Generating Capacity Curves 1950-1958", which is in Oroya and New York files. Since the submission of that report projected load increases have changed as regards magnitude, date and frequency of increments. In order to restate our conception of the problem, there have been prepared and are attached hereto two new graphs as follows:

Figure 2 - "Average and Maximum Demand Curves 1951-1960 and Proposed Firm Power Curve 1951-1960".

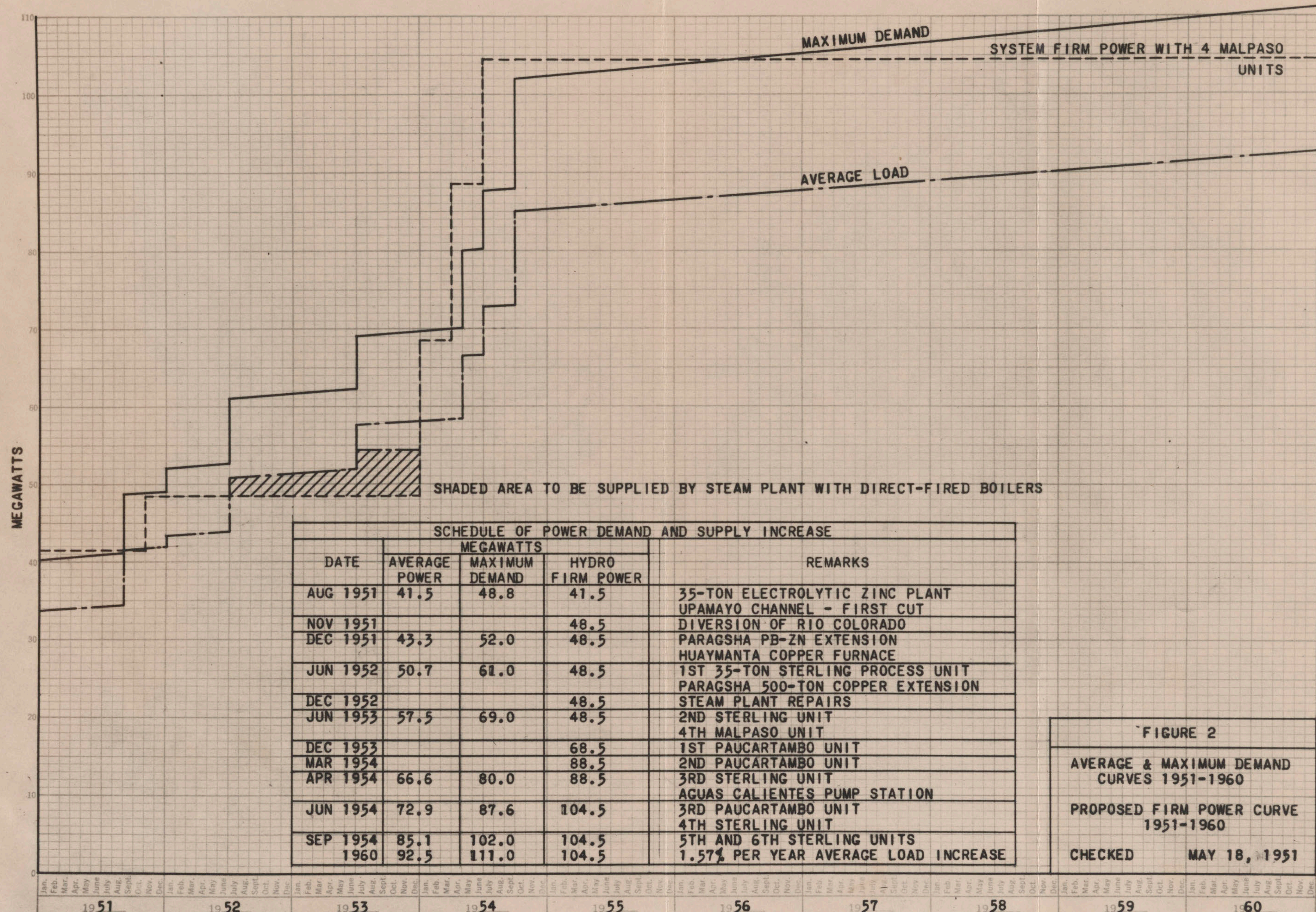
Figure 3 - "Maximum Demand Curve 1951-1960 and Peak Generating Capacity Curves 1951-1960".

These graph sheets are largely self-explanatory. Figure 2 has a table giving reasons for specific increases in power use and supply, and the dates on which such increases are expected to occur. Figure 3 is attached for the purpose of showing how each generating unit requested fits into the demand schedule. On the same sheet is a table which lists system peak generating capacities and those of component plants. All possible plant conditions are included in the table, and those of special interest are shown graphically.

Although to date, the system daily maximum demand has averaged 123% of daily average load, it is believed that in the future, system load peaks will have a lower ratio to average load than in the past. This belief is based on the assumption that the zinc plant will have an inherently high load factor. Cognizance of this situation has prompted the use of the multiplier 1.20, instead of 1.23, in the calculation of system maximum demand beginning August, 1951. Strictly speaking, the improvement in system load factor indicated by the multiplier 1.20 will not be effected at once, but will be felt in greater degree as the ratio of zinc plant load to existing load increases. In fact, the multiplier may even drop below 1.20 when all sterling units are on the line, but the use of a smaller one, unsupported by previous experience with the sterling process, is believed to be a potential danger in system planning.

When evaluating the attached graphs, it should be kept in mind that one of the chief functions of the Malpaso station is frequency control. It is therefore imperative that Malpaso's peak generating capacity be at least equal to and preferably greater than the load swings it has to handle. Malpaso's peak capacities are:

With 4 machines, peak load capacity is 4 x 13.6 = 54.4 mw.
With 3 machines, peak load capacity is 3 x 13.6 = 40.8 mw.
With 2 machines, peak load capacity is 2 x 13.6 = 27.2 mw.



SCHEDULE OF POWER DEMAND AND SUPPLY INCREASE

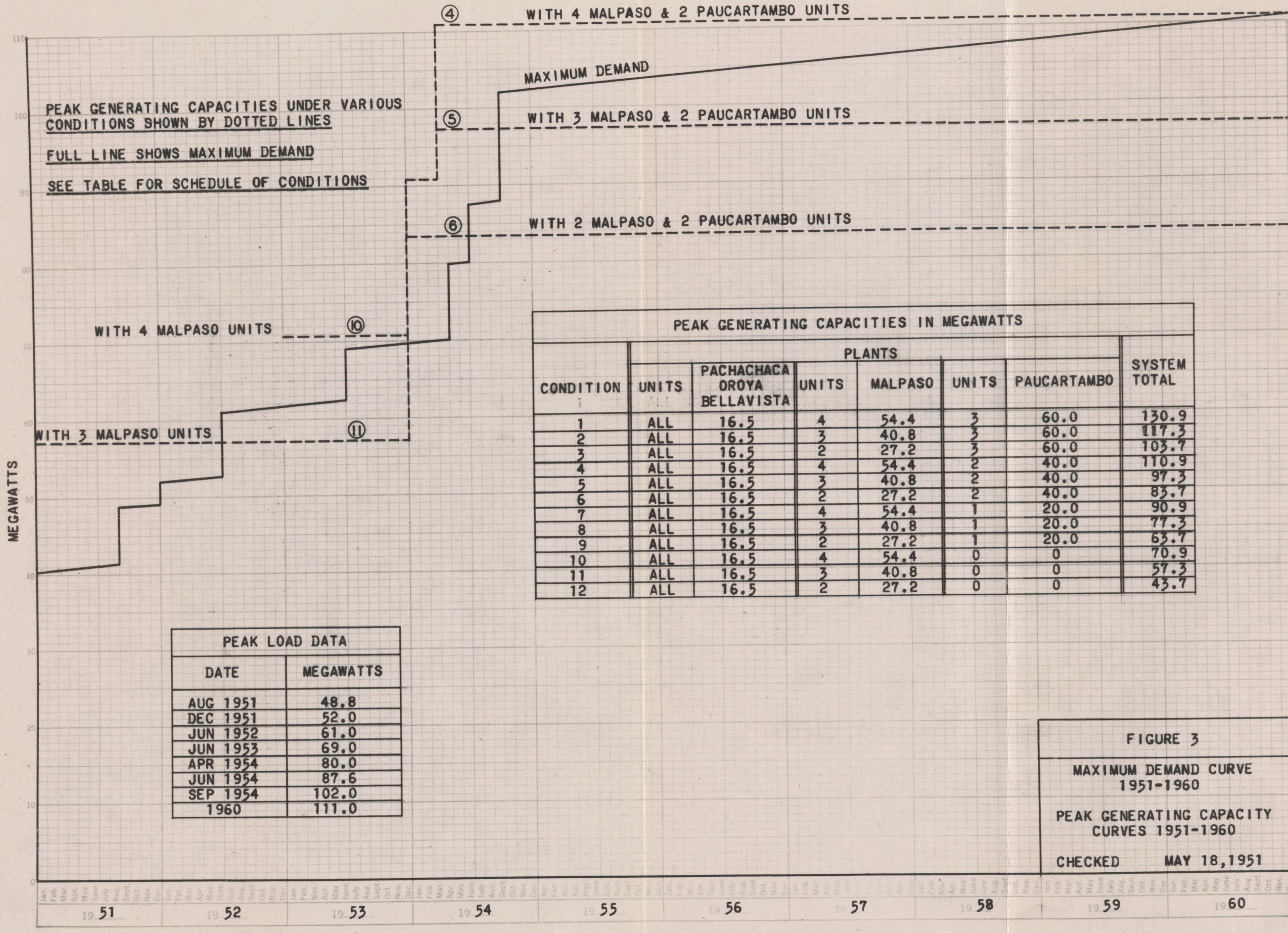
DATE	MEGAWATTS AVERAGE POWER	MAXIMUM DEMAND	HYDRO FIRM POWER	REMARKS
AUG 1951	41.5	48.8	41.5	35-TON ELECTROLYTIC ZINC PLANT UPAMAYO CHANNEL - FIRST CUT
NOV 1951			48.5	DIVERSION OF RIO COLORADO
DEC 1951	43.3	52.0	48.5	PARAGSHA PB-ZN EXTENSION HUAYMANTA COPPER FURNACE
JUN 1952	50.7	61.0	48.5	1ST 35-TON STERLING PROCESS UNIT PARAGSHA 500-TON COPPER EXTENSION
DEC 1952			48.5	STEAM PLANT REPAIRS
JUN 1953	57.5	69.0	48.5	2ND STERLING UNIT 4TH MALPASO UNIT
DEC 1953			68.5	1ST PAUCARTAMBO UNIT
MAR 1954			88.5	2ND PAUCARTAMBO UNIT
APR 1954	66.6	80.0	88.5	3RD STERLING UNIT AGUAS CALIENTES PUMP STATION
JUN 1954	72.9	87.6	104.5	3RD PAUCARTAMBO UNIT 4TH STERLING UNIT
SEP 1954	85.1	102.0	104.5	5TH AND 6TH STERLING UNITS
1960	92.5	111.0	104.5	1.57% PER YEAR AVERAGE LOAD INCREASE

FIGURE 2

AVERAGE & MAXIMUM DEMAND CURVES 1951-1960

PROPOSED FIRM POWER CURVE 1951-1960

CHECKED MAY 18, 1951



PEAK GENERATING CAPACITIES IN MEGAWATTS

CONDITION	PLANTS						SYSTEM TOTAL
	UNITS	PACHACHACA OROYA BELLAVISTA	UNITS	MALPASO	UNITS	PAUCARTAMBO	
1	ALL	16.5	4	54.4	3	60.0	130.9
2	ALL	16.5	3	40.8	3	60.0	117.3
3	ALL	16.5	2	27.2	3	60.0	103.7
4	ALL	16.5	4	54.4	2	40.0	110.9
5	ALL	16.5	3	40.8	2	40.0	97.3
6	ALL	16.5	2	27.2	2	40.0	83.7
7	ALL	16.5	4	54.4	1	20.0	90.9
8	ALL	16.5	3	40.8	1	20.0	77.3
9	ALL	16.5	2	27.2	1	20.0	63.7
10	ALL	16.5	4	54.4	0	0	70.9
11	ALL	16.5	3	40.8	0	0	57.3
12	ALL	16.5	2	27.2	0	0	43.7

PEAK LOAD DATA

DATE	MEGAWATTS
AUG 1951	48.8
DEC 1951	52.0
JUN 1952	61.0
JUN 1953	69.0
APR 1954	80.0
JUN 1954	87.6
SEP 1954	102.0
1960	111.0

FIGURE 3

MAXIMUM DEMAND CURVE 1951-1960

PEAK GENERATING CAPACITY CURVES 1951-1960

CHECKED MAY 18, 1951

In Figure 3, Condition No. 11 is of special interest. It shows that with only three Malpaso units, system peak generating capacity falls 12.0 mw below anticipated maximum demand in 1953. Condition No. 10 demonstrates that this undesirable situation could be corrected by installing the 4th Malpaso unit.

Condition No. 5, also illustrated graphically, indicates another deficiency. From the hydrograph of the Paucartambo River it is predicted that during the dry season the capacity of the Paucartambo plant will drop to 40 megawatts. This decrease in capacity is expected to last from $1\frac{1}{2}$ to 3 months, depending on the year. Under this condition, with only three generating units at Malpaso, the peak generating capacity of the system drops to 97.3 mw. Condition No. 4 shows that the 4th Malpaso unit corrects the deficiency.

Expressed in general terms, the 4th Malpaso unit, when installed, will enable the synchronized network as a whole to take advantage of Malpaso's extraordinary storage of 412,000 acrefeet (500,000 after diversion of the Rio Colorado and dredging Upamayo channel), and its pondage of 40,000 acrefeet.

Of equal importance from an operating viewpoint, is the part which would be played by the 4th Malpaso unit as a system spare. With it, any unit of the system could be shut down at will for routine maintenance. Without it, maintenance of the Malpaso and Paucartambo units could be effected only by reduction of system load which is of course synonymous with curtailment of production.

Assuming four units at Malpaso and three at Paucartambo, the maintenance schedule would be as follows:

Paucartambo units would be worked on, one at a time, during the driest part of the dry season when two units could utilize all the available water.

Malpaso units would be shut down one at a time for inspection and maintenance during the rainy season with all three units working at full load at Paucartambo.

Oroya maintenance work would be done during the rainy season with all units working at both Malpaso and Paucartambo.

Pachachaca and Bellavista units can be shut down, one at a time, at any convenient date because their installed capacities are greater than their firm capacities.

Figure 2 illustrates the fact that the steam turbine generators will be required to make an energy contribution to the system from June, 1952, until December, 1953, when the first Paucartambo unit is expected to go on the line.

POWER PROJECTS UNDER CONSTRUCTION OR APPROVED

1. The Paucartambo scheme is now in the development stage and scheduled to be in operation December 31, 1953.

2. The Malpaso 4th unit has been requisitioned for delivery in August, 1952.

3. New blades and nozzles have been ordered for the two Westinghouse steam turbines at Oroya steam plant.

COMPARISON OF PROJECTS

All the projects described under "Water Examinations" were under consideration as possible sources of power for the 200-ton zinc program.

Junin Tunnel, Corpacancha, Malpaso-Oroya Canal, and Rumichaca were eliminated because two or more of them would have to be built.

The Pachachaca-Oroya increase was rejected as being entirely inadequate, but it still has merits and may be developed later when creeping load growth or small new installations begin to overtax system capacity.

The Mejorada site was rejected because of its great distance (about 200 kilometers) from the load center.

Carpapata, to be feasible, would require the damming and control of about 20 lakes and ponds for storage. It seemed to be all head and no water.

Ingahuasi was turned down largely because it would be characterized by a high dam in earthquake country. Even if a safe dam, similar to Malpaso, could have been built, its design would have had to be preceded by long investigation of the site. Further, the construction of the dam itself would have been a long job, inherently.

The Mantaro Bend project, while undoubtedly the best and cheapest per unit of capacity if fully developed, was rejected because of its high first cost. It would require two or three years more to build than competing projects chiefly because its 16-kilometer tunnel could be driven from only two faces. It also seemed to have political complications in which Corporation executives did not wish to become involved.

The Paucartambo project appears to have several advantages over the others previously under consideration:

1. It has more than enough capacity for the zinc program.

2. It can be built in the shortest time of all projects considered. The reason for its inherently short construction period is that its 12-km tunnel can be split up into short segments by intermediate adits.

3. It imposes no safety hazard on people living downstream since no water of consequence is impounded by its 20 ft. dam.

4. It solves the Cerro low voltage problem through construction of the Carhuamayo substation.

ADDITIONAL POWER DEVELOPMENT

There is no doubt that there exists within transmissible distance from Oroya more undeveloped hydro power than the Corporation can ever use. The problem is not "where can power be found?", but "In what order ought potential projects to be developed?".

Power from storage.

Barring an all-out war, which would change everything, regardless of who won, it is assumed that the Corporation will spend until 1960 digesting its zinc program. Any load increase would therefore be small in relation to the 1954 system load as shown in Figure 2. For a slow growth of 10.0 megawatts superimposed on the "average load" curve, system firm power could be increased that amount through the development of additional storage for existing facilities:

1. Pachachaca - Oroya increase	6.0 mw
2. Storage for Paucartambo	4.0 mw
Total	10.0 mw

Artificial Nucleation.

No specific amount of power is assigned to this highly controversial source because it has not yet become an exact science. Although it has been demonstrated that the precipitation of moisture can be effected by the dispersal of silver iodide particles in the proper environment there exists great difference of opinion regarding the magnitude of the affected area. It is recommended that nucleation tests be made at once in Peru on a pilot basis. Until the conclusion of this test Hydroelectric Department planning will proceed along conventional lines.

New Plants.

The attached "Electric System Map" shows the locations of the Corporation's existing power plants and substations as well as potential power sites, both examined and unexamined.

Further Corporation expansion after 1960 would appear to be contingent on three developments:

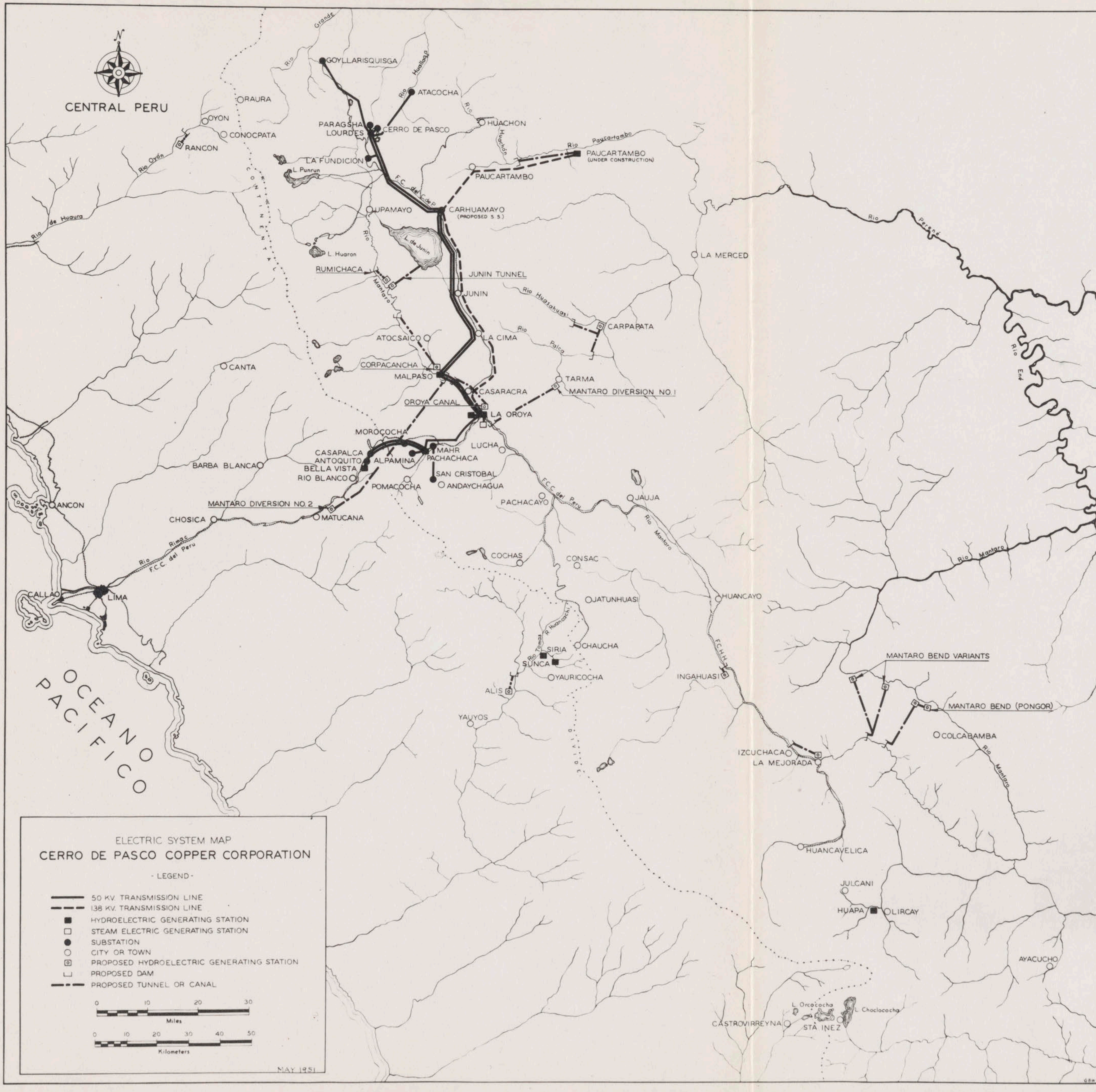
1. The success of the zinc program with the Corporation in a sound financial position.

2. Stabilization of international relations along capitalistic lines.

3. Friendly relations with the Peruvian Government.

Under the conditions stated above, limitations of Corporation expansion would appear to be only those of the imagination.

With a vigorous expansion policy in operation the logical site for development would be the Mantaro Bend or Pongor project. With power po-


CENTRAL PERU
N
GOYLLARISQUISGA
ATACOCHA
RAURA
OYON
CONOCPATA
RANCON
PARAGSHA
LOURDES
CERRO DE PASCO
HUACHON
LA FUNDICION
L. Punrun
PAUCARTAMBO
PAUCARTAMBO (UNDER CONSTRUCTION)
Rio Paucartambo
UPAMAYO
CARHUAMAYO (PROPOSED S.S.)
F.C. del C. de P.
L. de Junin
L. Huaron
Rio de Huaura
Rio Oyón
Rio Grande
Rio Huallaga
CONTINENTAL
LA MERCED
Rio Perené
RUMICHACA
JUNIN TUNNEL
JUNIN
Rio Huasahuasi
CARPAPATA
Rio Mantaro
ATOCSAICO
LA CIMA
Rio Palca
CANTA
CORPACANCHA
MALPASO
TARMA
MANTARO DIVERSION NO. I
CASARACRA
OROYA CANAL
LA OROYA
MOROCOCHA
LUCHA
CASAPALCA
ANTOQUITO
BELLA VISTA
ALPAMINA
MAHR
PACHACHACA
BARBA BLANCA
RIO BLANCO
SAN CRISTOBAL
ANDAYCHAGUA
POMACOCHA
ANCON
MANTARO DIVERSION NO. 2
MATUCANA
CHOSICA
PACHACAYO
F.C.C. del Peru
JAUJA
Rio Rimac
COCHAS
CONSAC
CALLAO
LIMA
JATUNHUASI
HUANCAYO
Rio Ené
Rio Mantaro
R. Huanachi
CHAUCHA
SIRIA
SUNCA
YAURICOCHA
ALIS
INGAHUASI
MANTARO BEND VARIANTS
MANTARO BEND (PONGOR)
F.C.H.H.
OCEANO PACIFICO
YAUYOS
COLCABAMBA
DIVIDE
IZCUCHACA
LA MEJORADA
ELECTRIC SYSTEM MAP
CERRO DE PASCO COPPER CORPORATION
- LEGEND -
50 KV. TRANSMISSION LINE
138 KV. TRANSMISSION LINE
HYDROELECTRIC GENERATING STATION
STEAM ELECTRIC GENERATING STATION
SUBSTATION
CITY OR TOWN
PROPOSED HYDROELECTRIC GENERATING STATION
PROPOSED DAM
PROPOSED TUNNEL OR CANAL
0 10 20 30
Miles
0 10 20 30 40 50
Kilometers
MAY 1951
HUANCAVELICA
JULCANI
HUAPA
LIRCAY
AYACUCHO
L. Orcococha
L. Choclococha
CASTROVIRREYNA
STA INEZ

tentialities up to 600 mw at our command, our power worries would be over forever.

The exploitation of the Mantaro Bend power site might conveniently be done in plant units of 200 mw, each with a water supply of 1000 cfs, up to a total of three equal units.

The acquisition of such water rights would certainly be contingent on the Corporation's willingness to sell power to all Central Peru including the cities of Jauja, Huancayo, Huancavelica and Ayacucho as well as the mining industry. There would be strong political pressure to supply power to Lima also. Electric power transmission over this distance from the plant, approximately 430 kilometers, might eventually be done, but it would require the use of high voltage of the order of 400 kilovolts, not yet standardized. Sale of power to Lima might be done by selling wholesale to Empresas Electricas Asociadas who have the Lima franchise.

Regardless of the technical problems involved, the supplier of power would be subject to government regulation. The supplier would, in effect, be organized as a public utility with corporate structure separate from that of the Corporation as a metal producer.

In view of the existing world predicament, it appears unlikely that the Utopian conditions previously named will come to pass in the foreseeable future. A realistic attitude demands that smaller projects closer to home be also considered.

The table below lists potential power sites, exclusive of Mantaro Bend, in the order in which they might be developed.

PROJECT	MW
Ingahuasi	45
Mejorada	50
Corpacancha	28
Carpapata	20 — 60

HYDRO PROJECTS NOT EXAMINED

Alternative hydro projects of a visionary nature have been proposed. These are noted on the Electric System Map as "Mantaro Diversion No. 1" and "Mantaro Diversion No. 2". The first of these visualizes a tunnel to divert Mantaro River water from Oroya to some point in the valley of the Rio Palca in the vicinity of Tarma. The second contemplates the diversion of the Mantaro from Malpaso tailwater through a tunnel to Rio Blanco with a further extension to Matucana or nearby point to secure head. Either would generate power of almost any magnitude required but are not discussed at length because no factual data concerning them are available. Either of the two would conflict with agricultural interests utilizing Mantaro water for irrigation in the Jauja district. Diversion No. 2 might conceivably be developed when the Lima water problem becomes sufficiently acute.

SUMMARY

1. The present system average load of 34 mw has an inherent growth factor of 1.57% per year without new capital expenditure and a peak to average power ratio of 1.23 to 1.0. The multiplier 1.20 is used in future peak load estimates.

2. The 200-ton zinc program with a projected 1960 average load of 92.5 mw and 1960 peak load of 111.0 mw will be amply supplied by the Paucartambo development.

3. The Malpaso 4th unit is required in order to realize the full potentiality of the Paucartambo plant and to serve as a system spare and peaking unit.

4. Hydroelectric potentialities in the vicinity of Oroya are adequate to supply all possible future loads.

5. The Mantaro Bend project is technically superior to all others discussed but has political complications which should be carefully appraised previous to serious consideration of the site.

6. A sense of realism suggests that future power development be commensurate in capacity with predictable load increments.

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APPENDIX A

Thermal Electric Plant.

While no steam plant is recommended for inclusion in the power program, this discussion is inserted to show that power from steam-driven prime movers has been considered and definitely stricken from the agenda.

Ebasco Services, Inc., have kindly furnished power production figures which are a condensation of costs prevailing in all Electric Bond and Share-owned steam plants.

STEAM-ELECTRIC STATIONS
PERFORMANCE AND PRODUCTION COSTS

	BUILT IN		
	1929	1943	1950
Average, all stations, BTU per net Kw-hr.	20,000	18,700	13,900
Best station, " " " " "	16,000	11,900	11,090
Best unit " " " " "	14,500	11,600	11,090
Average production costs, mills per net Kw-hr.	3.6	3.2	2.8
Average fuel costs " " " " "	2.5	2.2	2.0
Average other than fuel costs " " " "	1.1	1.0	0.8
Best station production costs " " " "	1.4	1.1	1.0

It is assumed that a steam plant at Callao could duplicate but not improve on the average of all plants built by Ebasco in 1950, which is 2.8 mills. Cerro de Pasco now produces power at a cost of 1.0 mill per Kw-hr., including the cost of water examinations.

The above production costs do not include fixed charges.

The Power System

Three Hydroelectric and One Steam-Electric Plants

By R. McDonald and B. C. Maine

Respectively Superintendent and Assistant Superintendent of Power; Members, A. I. E. E.

CERRO'S power system consists of three main hydroelectric plants and one steam-electric plant. These are located on the eastern slope of the main Andes range at altitudes between 12,000 and 13,000 ft. The hydroelectric group utilizes the watershed which extends for about 150 kilometers south from Cerro de Pasco, divided into two catchment areas which lie adjacent. The northern area serves the medium-head plant of Malpaso, while the southern area provides for the high-head plants at Pachachaca and Oroya.

The rainfall, as registered at the rain gauging stations of the three hydroelectric plants, averages 33 in. per year; all these stations are subject to the same hydrological conditions, and the bulk of precipitation occurs between October and March. Rainfall during the dry season, April till September, has no appreciable effect on the total annual runoff.

Table 1 shows the storage capacities of the main reservoirs of the hydroelectric group.

The four plants are tied together electrically by a 50-kv. transmission network, the system being 3-phase 3-wire at 60 cycles with a solidly grounded neutral, and with a total installed capacity of 84,750 kva.

TABLE 1. UTILIZABLE WATER STORAGE

High Head		Medium Head	
Reservoir	Acre-feet	Reservoir	Acre-feet
Lake Huallacocha Alta	900	Lake Junin	412,000
Lake Huallacocha Baja	9,200	Lake Malpaso	40,000
Lake Pomacocha	21,400	Lake Punrun	40,000
Lake Huacracocha	2,040		
Lake Huascacocha	3,500		
Total	37,040	Total	492,000

NOTE: Other lakes tributary to the Yauli and Mantaro Rivers are uncontrolled and the flow from them in the wet season is utilized while the main reservoirs are partly or totally closed off.

Malpaso dam passing 4500 second feet of water.

Individual plants

The Oroya hydroelectric plant was the first installed, and went into operation in 1914. It has a total capacity of 11,250 kva., consisting of three horizontal Allis-Chalmers generators direct connected to Pelton-type impulse turbines with deflecting-type nozzles controlled by belt-driven governors. The head on the plant is 720 ft.; the units operate at a speed of 300 r.p.m.

The water supply for the plant comes from the Yauli River, the intake being at La Toma. It is conveyed by an earth ditch 16 km. long to the Oroya forebay, which has a pondage capacity of 45 acre-feet. A steel penstock approximately 4000 ft. long extends between the forebay and the powerhouse where it branches to the three units.

Generators are star-connected with solidly grounded neutral, and generation is at 2400 volts. Excitation for the generator fields is supplied by two Allis-Chalmers water-wheel or motor-driven, 125-volt, d.c. generators, either of which is capable of total plant excitation. Generator voltage is stepped up directly through General Electric transformers to the 50-kv. network. Each transformer bank consists of three 1000-kva. single-phase units connected delta-star with solidly grounded neutral. Protection is provided for generators and transformers by differential and induction-type overload relays.

As previously stated, the Oroya hydro

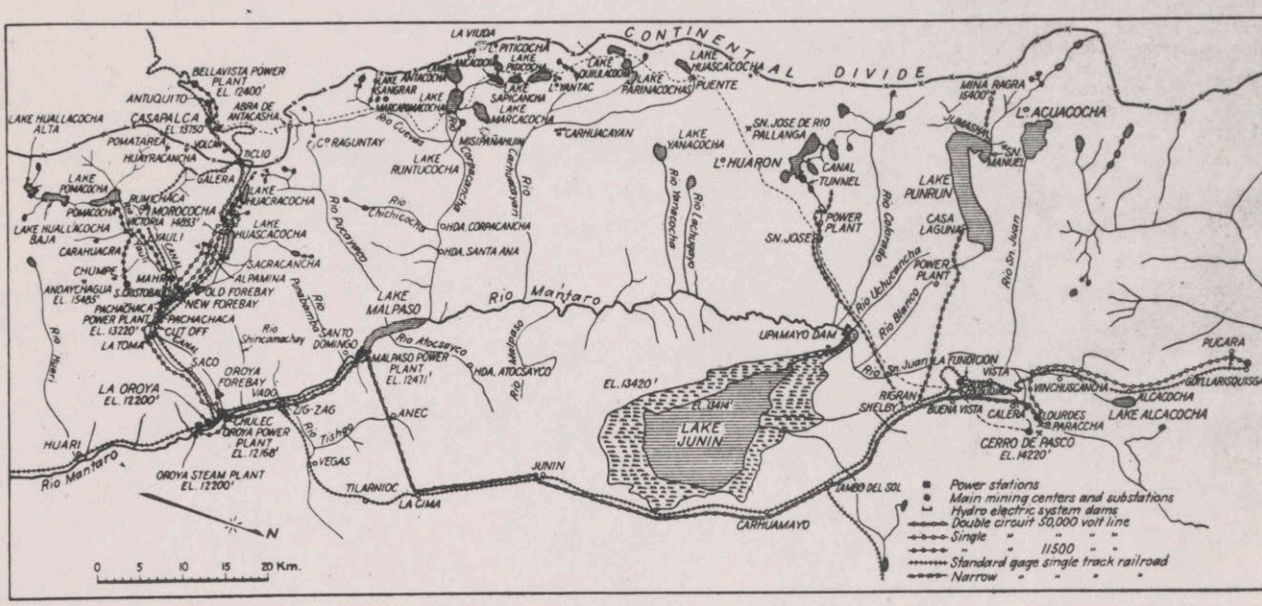

Fig. 1. Map of Cerro de Pasco power system.

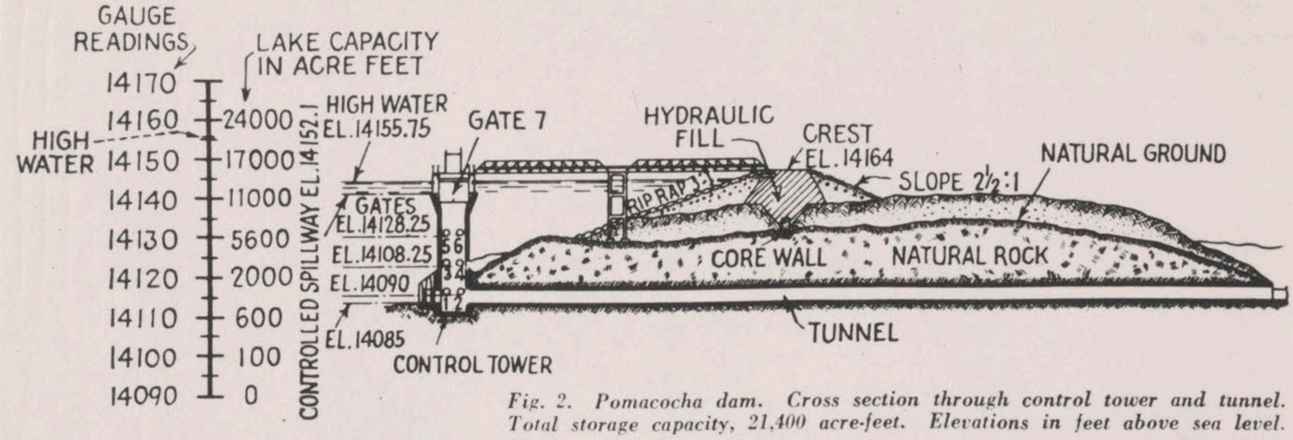

Fig. 2. Pomacocha dam. Cross section through control tower and tunnel. Total storage capacity, 21,400 acre-feet. Elevations in feet above sea level.

plant was the first installed, and from it has grown the present system.

The Pachachaca hydroelectric plant has four units consisting of impulse turbines, generators, transformers, and exciters identical to those described for the Oroya plant. The station is connected in a similar manner as Oroya to the 50-kv. network, but differs slightly from the Oroya plant in that it has a 2400-volt generating tie bus. The first unit installed at Pachachaca went into service in 1919; the other three units were an addition to the original installation and went into operation in 1927. Water supply for Unit No. 1 comes from the Morococha lake district where water is impounded by dams on Lakes Huacracocha and Huascacocha, and at Old Forebay. Lakes and the forebay are interconnected by natural streams. From Old Forebay, water is conveyed to Unit No. 1 via a combination redwood-stave pipe line and steel penstock, a distance of approximately four kilometers.

Water supply to the other three units, namely 2, 3, and 4, is from the headwaters of the Yauli River where it is impounded by dams at three reservoirs; Huallacocha Alta, Huallacocha Baja, and Lake Pomacocha. These reservoirs are interconnected by natural streams. Water is conducted to New Forebay from Pomacocha Dam via a concrete flume 18 km. long. Three steel penstocks connect Units 2, 3, and 4 with the New Forebay, which has a pondage capacity of about 25 acre-feet.

Pomacocha Dam went into service in September 1941. It is hydraulic-fill type, with a total length of 1300 ft. The dam is not provided with a spillway over it, and excess water is passed through a circular control gate located on top of the intake tower. Spilled water is dissipated downstream from the dam, and regulated by a gate at the entrance to the Pachachaca concrete flume.

The latest addition to the system was the Malpaso plant; which went into operation in 1936. This plant utilizes a tributary of the Amazon, the Mantaro River, the main source of which is Lake Junin. The latter lake is dammed at its outlet by a masonry and concrete structure, which gives a lake regulation of 7 ft. drawdown.

Controlled water from the Upamayo Dam flows downstream approximately 90 km. to the Malpaso Dam, the latter providing an operating head of 250 ft. for the plant.

Referring to Fig. 3, it will be noted that the structure is a high rock-fill dam. It is located approximately 24 km. upstream from the smelter town of Oroya. The dam is situated between the walls of a narrow gorge of porphyry intruded in the prevailing sedimentary rocks of the region which appear at the surface in this area. The dam is unusual in design in that its main body rests on the yielding material of the old river bed. The concrete cutoff wall is 105 ft. deep, extending from the river-bed level to the live rock at the bottom of the gorge.

The upstream section of the dam consists of a derrick-laid rock mass which tapers from a bottom thickness of 150 ft. to a top thickness of 12 ft. This section has an upstream face of laid-up rubble masonry bound by ce-

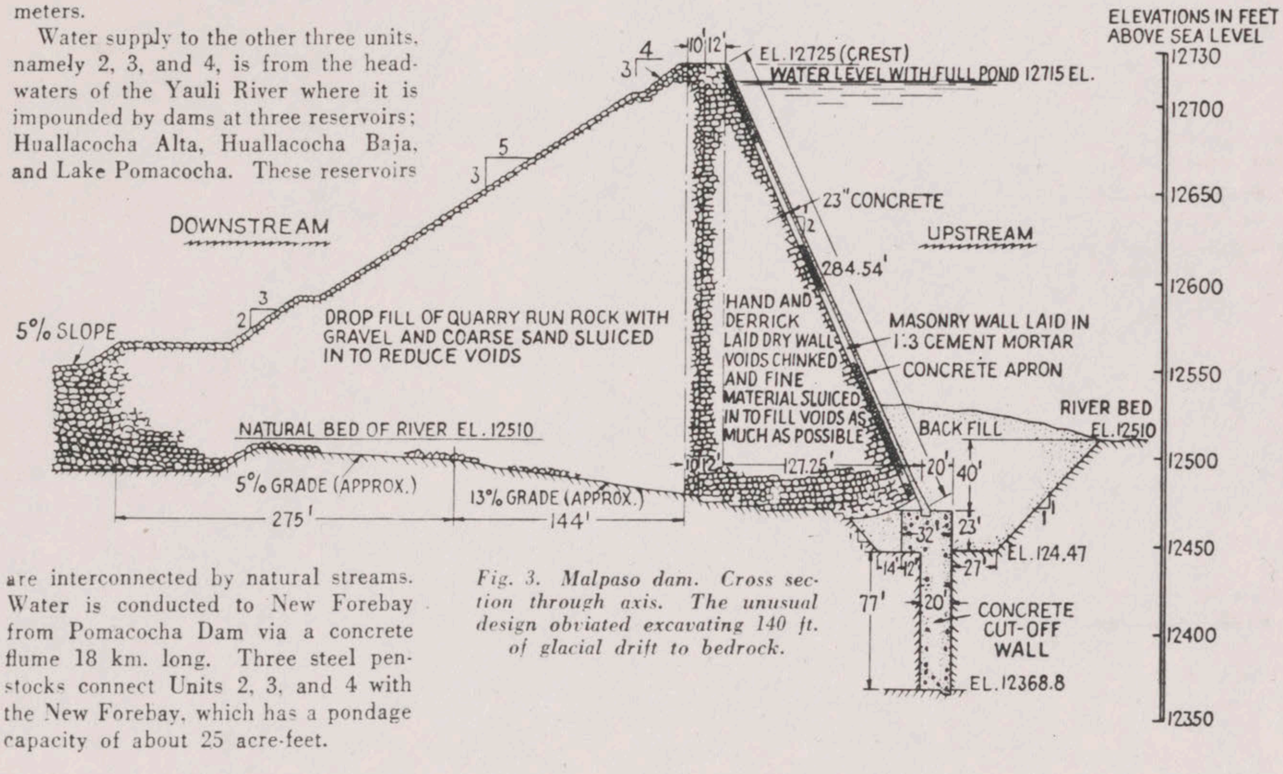

Fig. 3. Malpaso dam. Cross section through axis. The unusual design obviated excavating 140 ft. of glacial drift to bedrock.

R. McDonald

B. C. Maine

ment mortar. As a water seal, a reinforced concrete apron is placed from the cutoff wall to the crest of the dam.

The dam was constructed so as to allow a certain amount of settlement, because of the nature of the materials used. A careful record is kept of all movements, and, after nine years of service, these movements have practically ceased. To date, the total downstream movement at the axis, as measured at the crest of the dam, has been 2.485 ft., while the settlement at the same point has been 1.225 ft. Settlement through the years has been symmetrical about the axis.

From the dam, a concrete-lined pressure tunnel about 7500 ft. long delivers water to the powerhouse. The lower end of the tunnel is branched into four take-offs, three of which are in use, with the fourth in reserve for an additional unit. Connected to the tunnel, is a differential surge tank located near the powerhouse, to absorb surges due to changes in water-flow velocities caused by turbine-gate movements.

Each of the three generating units now in service consists of an S. Morgan Smith vertical-shaft Francis-type water turbine, with a rated capacity of 18,600 hp. when operating at 257.14 r.p.m. under a net head of 250 ft. The turbine is direct-connected to a General Electric generator with an output capacity of 17,000 kva. at 6900 volts, 0.8 power factor. The turbine gates are controlled by a motor-operated S. Morgan Smith governor actuated by oil pressure.

Generators are star-connected with a grounded neutral in which has been inserted curent-limiting resistance. Excitation for the generator fields is supplied by direct-driven exciters mounted on top of the generator shaft, a pilot and main exciter being used. An induction-type voltage regulator is used to control excitation voltage. Generator voltage of 6900 is stepped up directly through General Electric 3-phase transformers to the 50-kv. transmission network; they are connected delta-star with a solidly grounded neutral.

The Oroya steam-electric plant is operated from a boiler plant actuated by waste heat from the reverberatory furnaces of the smelter; in emergencies, oil-firing is applied to the boilers. It consists of two Westinghouse 3750-kva. turbogenerators operated at a steam pressure of 175 lb. per sq. in. Generators are tied together electrically by a 2400-volt sectionalizing bus, synchronized with the hydroelectric system 2400-volt bus through a bus-tie oil circuit breaker.

Operation of system

At each of the four plants, hourly readings are taken throughout the 24 hours and recorded on a daily log sheet. These readings include routine generator plant data, equipment temperatures, etc., and for the hydro plants, the water-supply information pertinent to it, such as gauge readings at dams, canals, and forebays. In turn, these data are transmitted by phone to the control station at Oroya, where a detailed log sheet of the entire system covering generation, transmission, water supply, and weather conditions is recorded up to the hour. Every case of unusual trouble is reported minutely and recorded with all relative facts so that measures can be taken to prevent a recurrence. Operators at the Oroya hydro station supervise water regulation to all plants and load dispatching for the system.

The average hourly output for the system in 1944 was 26,176 kw. System load factor, expressed as hourly maximum peak power to daily average power, averaged 89 per cent for the year 1944. System power factor averages 90 per cent. System frequency of 60 cycles is controlled and maintained by the Malpaso station.

All oil circuit breakers on the 50-kv. network at Malpaso and the Oroya switching station, and four of those on the incoming and outgoing lines at Pachachaca, have interrupting capacities of 500,000 kva.

Transmission system

All transmission lines of the system run through rough, mountainous terrain and are subject to the atmospheric conditions typical at a latitude of 12° S. and at altitudes ranging from 12,000 to 16,000 ft. They are exposed to snow and lightning storm hazards. The total length of the 50-kv. double-circuit transmission lines is 162 km.; of the 50-kv. single-circuit lines, 85 km.; and of the 11-kv. single-circuit lines, 15 km.

The supporting structures for all

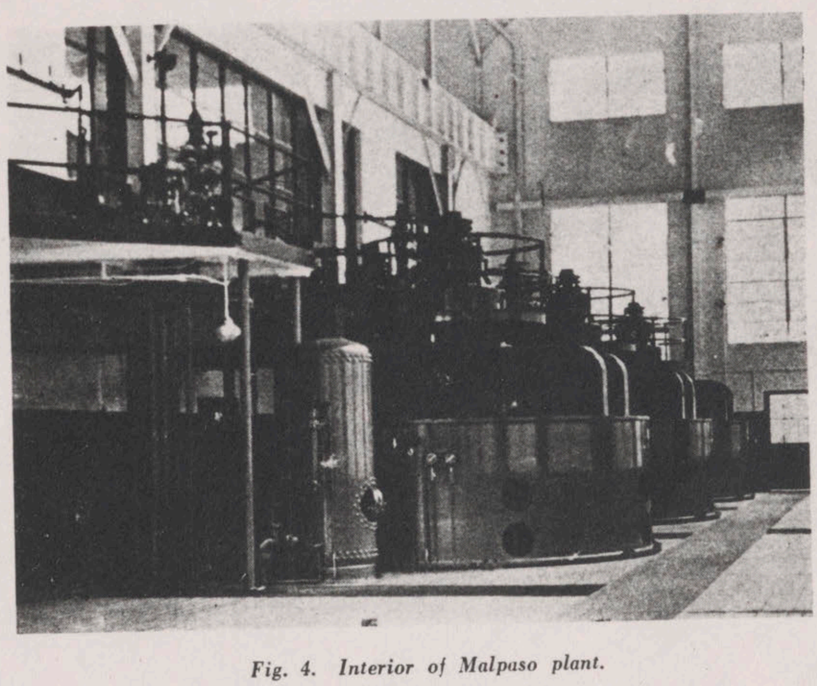

Fig. 4. Interior of Malpaso plant.

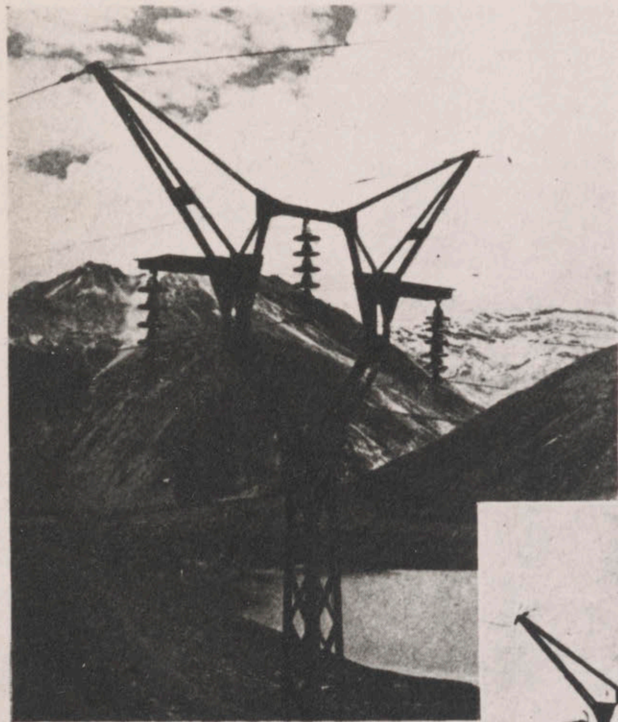

Fig. 5. Type of square steel pole.

Fig. 6. Pole with flexible steel frame.

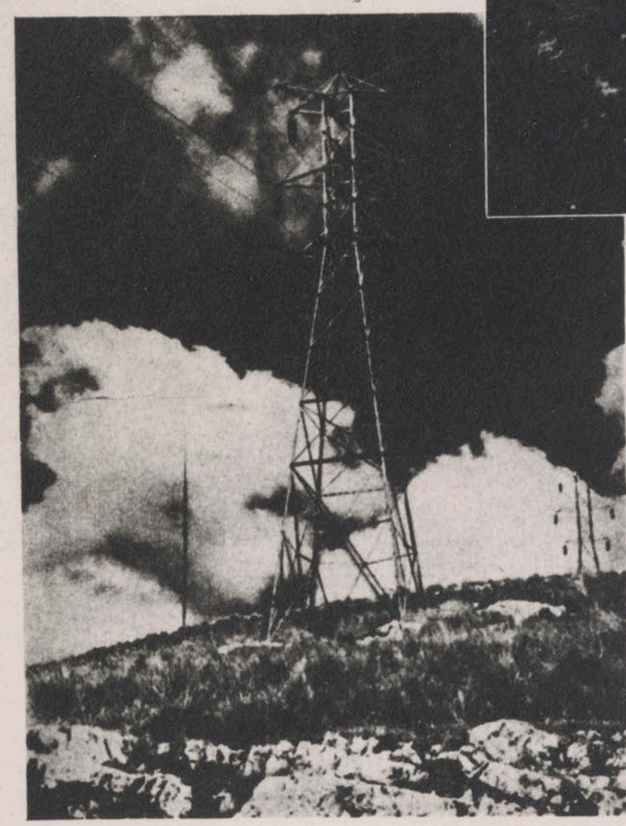

Fig. 7. Rigid, wide-base steel tower.

lines are of steel, and are divided into three classes: (1) the steel pole, (2) the flexible steel frame, (3) the rigid, wide-base steel tower.

Spacing between conductors varies from a minimum of 6 ft. to a maximum of 10 ft., according to the types of supporting structures and the configuration of conductors. All lines are shielded from lightning with double overhead ground lines and, in the sections most affected by lightning, lightning diverter rods have been erected adjacent to the lines. Buried structure-to-structure counterpoises have also been installed in the latter sections. Lines are protected at their extremities and at all sectionalizing switching stations by lightning arresters, and, in certain sections, expulsion protector tubes have also been installed. All transmission lines are patrolled daily, and the line crews for maintenance and repairs are stationed permanently at strategic points of the system.

At present, an investigation of lightning characteristics at high altitudes is being conducted by the hydroelectric department under the direction of the International General Electric Co., who have furnished the apparatus. The investigation includes the measurement of lightning-stroke amperages and surge voltages on transmission lines.

Distribution and utilization

Power is stepped down from 50,000 volts to 2300 volts for distribution at receiving substations. These substations redistribute power for local requirements at the smelter, mines, and concentrators. The bulk of power used is at 2300 volts, practically all motors over 50 hp. being at this voltage. Data pertaining to reception and distribution of power is recorded hourly on daily log sheets at all substations, and attendants receive switching orders from system operators.

All properties receiving power have fully-organized electrical departments capable of undertaking any electrical repairs or installations. Most coils used in motor and transformer repairs are wound and treated in a central winding department at Oroya.

A feature not properly included in the power network but complementary to it is a telephone system consisting of sixteen central exchanges, 700 telephones, and 900 miles of double-circuit line, facilitating maintenance, load-dispatching, and general communication among the properties.

Surveys already made of the hydrology of this region and of heads available, indicate that sufficient hydraulic power remains undeveloped near at hand to take care of future power requirements.

being thus aggravated, in turn, and something of the desert character being ultimately imparted to regions that were naturally verdant and productive, prior to devastation through prodigal spending and unwise use of the fertile soil and its protective covering. Such wanton waste of soil and water tends to establish a vicious circle to aggravate the situation, from which a region may be rescued only through years of well-organized, scientifically directed conservation programs.

Evaporation. The ultimate measure of atmospheric moisture available for precipitation is evidently the moisture capacity of the atmospheric column plus the rate at which it may be replenished with water vapor. Included among the accountable phenomena are evaporation from water, soil, rock, and other moist surfaces; sublimation of snow and ice; transpiration from plant foliage; exhalation from biological organisms, products of combustion, and mechanical power generation; and occasional volcanic eruptions. Because of the dominant role of evaporation from water, constituting nearly three-fourths of the surface of the globe, it seems appropriate to make this the basis of reckoning and comparison.

By recalling that the average insolation or radiant solar energy reaching the earth's atmosphere would be capable of evaporating nearly 0.8 in. per day in equatorial regions if no interceptions or losses intervene and making due allowance for the curved surface of the sun-lighted hemisphere (with a total area double that of the great circle), it is obvious that not more than 0.4 in. depth of water could be transformed into vapor daily over the entire surface of the globe if the solar energy were devoted solely to this process. However, with nearly half the insolation intercepted by clouds, floating dust particles, and intervening atmosphere, and with further percentages deducted from the single two-billionth part of the solar output intercepted by this planet, to be absorbed by the earth's surface and surroundings, only about 30 per cent of the total insolation is employed to evaporate approximately 0.12 in. per average day, over the entire surface of the globe. This amounts to nearly 43 in. annually for the entire area, but varying from possibly 6 in. or less at the poles to nearly 100 in. at a number of stations in the lower latitudes and attaining somewhat higher annual totals in the midst of distinctly arid regions, as illustrated by both evaporation and rainfall records shown in Tables 1, 2, and 3.

Atmospheric Moisture Capacity. The process of evaporation, like that of transpiration, operates more or less continuously, but at various rates corresponding to the changes in exposure to solar radiation, temperature of both air and water, wind movement, and relative humidity there prevailing. Reference to Table 4, Moisture Capacity of Atmosphere at Various Temperatures, indicates that the total water content of the atmospheric column with a temperature of 50F at its base would probably not exceed 0.58 in., whereas for a corresponding temperature of 100 deg, the moisture subject to precipitation could be as high as 3.62 in. It is thus apparent that the atmospheric moisture capacity varies directly with some power of the temperature (nearly the square of degrees Fahrenheit) and therefore with potential evaporation rates.

Release of water vapor into the air displaces corresponding volumes of atmosphere by a substance only 62 per cent as heavy, vertical circulation being thus ensured owing to the inherent buoyancy of vapor—somewhat comparable to the upward motion of small bubbles through a liquid. Continued evaporation under ordinary circumstances and moderate temperatures will probably overtax the moisture capacity of the atmospheric column within a fortnight or thereabout, unless the lateral circulation should bring other air masses with additional capacity, *i.e.*, with lower relative humidity. Wind movements may and ordinarily do convey the vapor to distant locations and thus account for precipitation in regions quite remote from its origin. If a cubic foot of air near sea level, at 100F, has six grains of water vapor intermixed

(a medium drop of water would have equal weight), it would produce about 30 per cent saturation. If the temperature of the air mass falls to 70 deg, the percentage of saturation rises to 77 per cent; at 60 deg, complete saturation is reached, or the dew point is attained, and condensation is produced; and at 40F, slightly more than half the moisture will have fallen.

Evidently, the total inflow of moisture into the atmosphere during a given period, represented mainly by evaporation, will be equaled by outflow, or precipitation, during the same period, except for the few inches of varying reserve or storage within the atmospheric column as shown in Table 4. Considering both the average and extremes of prevailing temperatures as affected by seasons, latitude, altitude, and the daily insolation, it appears that a 6-in. depth of moisture may be held temporarily by tropical air masses, whereas the average over the entire globe may not exceed a 2-in. depth.

Rainfall. Precipitation provides the required outlet for water-vapor content beyond the moisture capacity of the given air mass for the prevailing temperature. As indicated in the foregoing, the natural buoyancy of vapor intermixed with air produces a definite upward movement, resulting in cooling with altitude and expansion under reduced pressure. This upward component of air movement and attendant rate of cooling may be suddenly increased by the interposition of barriers such as cold, relatively dense air masses, by high ground and orographic features, or by a combination of underrunning polar air and mountain ridges causing abrupt deflection of air currents. Such accelerated cooling is the immediate factor producing most of the precipitation, appearing mainly as rainfall, but with restricted localities supplied in varying proportions by such forms as snow, hail, dew, and condensation from fog. Although the latter two forms of precipitation represent but small daily contributions and are not readily susceptible of measurement, the total annual depths may be considerable. Moreover, such condensations of moisture from the atmosphere, night after night, account for the freshening and revival of foliage and vegetation after seemingly hopeless wilting under bright sunshine and thus constitute vital influences in plant growth under some conditions.

Figures 1 to 5 graphically portray rainfall characteristics, including for convenience all forms of precipitation under the single heading, at selected representative stations throughout the world. More detailed data concerning these and other stations in various countries are shown in Tables 2 and 5.

Bearing in mind that an even distribution of precipitation over the entire surface of the globe would require average annual depths variously estimated from 40 to 44 in., in order to dispose of annual accretions from evaporation, we have to deal in actuality with widely varying amounts, ranging from less than 4 in. at Yuma, Ariz., to more than 100 in. at selected high mountain stations on the Pacific Coast, and more than 200 in. annually on the windward slopes of high mountains in or near the tropical zone, culminating at Cherrapunji, northeastern India, in some 450 in. average, and more than double that amount for the maximum year of record. Such overabundant rainfall as that at the latter station, more than ten times the average for the globe, connotes the existence of a high, abrupt barrier of Himalayan proportions, including Mt. Everest, a fluelike pass therein that induces almost a continuous flow of moisture-laden air masses from tropical seas, and great areas of scarcity in precipitation, such as the plateau of Tibet and the desert of Gobi. Similarly, some stations on the Olympic Peninsula of Washington receive measurable depths of rainfall on most of the days throughout the year; they are located on a mountainous barrier crossing the path of tropical Pacific air masses, which in turn yield but sparingly to the Columbia Basin after their prodigal spending while crossing the successive mountain ranges.

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TABLE 1.—RECORD OF EVAPORATION RATES
(All depths in inches)

Station	Years of record	Maximum			Mean	Annual			Remarks
		Day	Mean month	Month	April to September	Minimum	Mean	Maximum	
Gardiner, Me	3	..	5.0	5.8	22.8	..	26		
Boston, Mass	15	..	6.0	7.4	28.6	31	39	48	
Rochester, N. Y	25	..	4.7	6.9	....	26	31	39	
Washington, D. C	3	..	....	7.0	32.2				
Chapel Hill, N. C	4	..	5.3	7.5	....	...	40		
Charleston, S. C	20	..	5.7	8.6	....	30	47	66	Reservoir
Charleston, S. C	19	..	10.4	....	....	...	88	...	Land pan
Birmingham, Ala	..	..	7.5	....	38.3	...	51		
California, Ohio	..	..	7.2	....	35.5	...	46		
Cleveland, Ohio	6	..	....	....	24.6				
Detroit, Mich	4	..	....	....	32.1				
Thunder Bay, Mich	4	..	....	....	30.2				
Milwaukee, Wis	5	..	....	....	26.9				
Lake of the Woods, Minn	3	..	3.5	....	20.7				
Columbia, Mo	2	..	....	7.5	31.2	...	50		
Crowley, La	7	..	6.2	....	32.3				
Laredo, Tex	1	..	....	13.7	68.4				
San Antonio, Tex	11	..	9.6	....	46.0				
Austin, Tex	2	..	....	11.0	47.3	...	68		
Amarillo, Tex	11	..	10.4	....	52.7				
Big Springs, Tex	3	..	12.7	....	59.0				
Dalhart, Tex	10	..	10.6	....	55.4				
Lawton, Okla	3	..	9.0	....	45.6				
Woodward, Okla	4	..	10.8	....	49.5				
Garden City, Kans	10	..	10.9	....	52.8				
Hays, Kans	11	..	10.0	....	47.9				
North Platte, Neb	11	..	9.1	....	43.6	...	54 ±		
Lincoln, Neb	11	..	....	....	34.8				
Newell, S. D	16	..	8.1	....	36.6				
Edgeley, N. D	11	..	6.4	....	29.6				
Mandan, N. D	5	..	7.4	....	33.3				
University, N. D	16	..	5.7	7.1	26.2				
Huntley, Mont	13	..	7.5	....	32.8				
Moccasin, Mont	9	..	7.1	....	32.8				
Archer, Wyo	5	..	7.9	....	36.3				
Laramie, Wyo	6	..	....	....	39.4				
Fort Collins, Colo	16	..	....	....	29.3				
Akron, Colo	10	..	9.1	....	42.7				
Grand Valley, Colo	1	..	....	....	36.5				
Rocky Ford, Colo	1	..	....	....	61.6				
Tucumcari, N. M	6	..	10.9	13.8	55.4				
Santa Fe, N. M	2	..	....	11.9	52.5				
Elephant Butte, N. M	7	..	14.3	....	....	90	102	110	
Elephant Butte, N. M	2	..	....	16.9	75.8				
Elephant Butte, N. M	..	..	13.5	....	....	...	87		
Carlsbad, N. M	4	..	....	12.4	69.4	...	107	...	In city
Carlsbad, N. M	4	..	....	11.1	....	...	94	...	In alfalfa field
Lake Avalon, N. M	10	..	10.0	12.9	....	66	73	83	
Las Cruces, N. M	3	..	....	....	40.1				
Holbrook, Ariz	5	..	....	8.6	47.0				
Roosevelt Reservoir, Ariz	7	..	13.4	14.8	67.0	82	87	95	
Granite Reef, Ariz	1	..	....	12.7	....	...	98	...	Tank floating in river
Granite Reef, Ariz	1	..	....	14.3	....	...	115	...	Tank on ground
Mesa, Ariz	2	..	12.2	....	56.2	...	91		
Tucson, Ariz	3	..	....	....	54.2				
Yuma Desert, Ariz	3	..	17.5	....	....	114	123	136	
Yuma, Ariz	9	..	10.6	....	55.1	...	96		
Yuma, Ariz	5	..	10.4	....	....	70	76	88	Alfalfa field
Nephi, Utah	10	..	9.5	....	44.6				
Spanish Fork, Utah	5	..	9.6	....	38.8				
Fort Douglas, Utah	3	..	....	....	30.7				
Aberdeen, Idaho	6	..	9.6	....	42.1				
Arrowrock, Idaho	8	..	....	10.2	42.0				
Deer Flat, Idaho	8	..	8.0	....	38.1	...	96		
Minidoka, Idaho	..	..	....	15.0	....	...	96		
Walla Walla, Wash	2	..	....	9.5	38.0				

TABLE 1.—RECORD OF EVAPORATION RATES.—(*Continued*)

Station	Years of record	Maximum			Mean	Annual			Remarks
		Day	Mean month	Month	April to September	Minimum	Mean	Maximum	
North Yakima, Wash	..	....	....	10.7	....	...	68		
Lake Kachess, Wash	8	....	....	6.1	23 ±	...	33		
Klamath, Ore	4	....	8.5	9.2	....	...	51		
Hermiston, Ore	6	....	8.5	11.1	36.6				
Hermiston, Ore	..	....	8.4	....	....	...	44		
Moro, Ore	7	....	9.3	....	41.0				
Fallon, Nev	16	....	10.7	....	50.9	61	64	73	
Fallon, Nev	..	....	....	9.9	....	...	54	...	Tank floating in canal
Lake Tahoe, Calif	7	....	4.9	6.5	....	20.5	30	40.1	
Lake Tahoe, Calif	8	....	5.9	....	....	...	40		
Biggs, Calif	4	....	9.6	....	....	...	44		
Sweetwater, Calif	7	....	....	9.0	....	49	54	59	
Cuyamaca, Calif	9	....	....	....	....	45	57	85	
Fresno, Calif	..	....	....	....	....	...	66		
Los Angeles, Calif	..	....	....	....	....	...	37		
San Diego, Calif	..	....	....	....	....	...	38		
Mammoth, Calif	..	....	....	18.0	....	...	126		
Owens Lake, Calif	..	....	....	....	....	...	61		
Christiansted, V. I	8	....	8.2	....	45.2	74	78	84	
Assuan, Egypt	3	....	....	....	....	...	107		
Bombay, India	..	....	....	....	....	...	96		
Van Wijks Vlei, South Africa	14	....	....	....	....	...	67		
Kimberley, South Africa	8	....	....	....	....	79	89	93	Vaal River
Kimberley, South Africa	8	....	....	....	....	...	55	...	Deep reservoir
Bloemfontein, South Africa	..	....	....	....	....	66	...	82	Exposed to wind
Bloemfontein, South Africa	..	....	....	....	....	48	...	58	Sheltered from wind
Johannesburg, South Africa	..	....	....	....	....	...	75		
Capetown, South Africa	..	....	....	....	....	...	79		
Port Elizabeth, South Africa	..	....	....	....	....	32	...	46	
Alice Springs, Australia	24	0.88	12.5	15.5	....	34	96	108	
Adelaide, Australia	47	0.62	9.0	11.2	....	47	54	61	
Eucla, Australia	6	0.52	7.0	8.3	....	53	58	61	
Brisbane, Australia	3	0.48	....	8.2	....	49	51	55	
Blackall, Australia	4	0.70	11.5	13.0	....	77	83	92	
Boulla, Australia	3	0.91	....	16.7	....	...	111	125	
Murrumbidgee, Australia	5	....	....	....	....	29	37	45	

tudes, duration, probability of occurrence, and, within ever-widening limits of forecast, the basis for their definite prediction are gradually emerging from the realm of the unknown. These facts should stimulate further research along the lines of logical and scientific approach, the most lucid and helpful presentation, and the most authoritative interpretation in the light of all available experience, and under the most mature guidance, in our dealings with hydrologic problems and their ramifications among the vital processes related to or constituting life, growth, well-being, and progress.

Research and operations in the hydrologic field have now entered the most productive and promising phase of their development and application of which we have definite knowledge; and presumably the rich harvest has only well begun.

Ady

Evaporation from Deep Water. — The temperature of large deep bodies of water varies considerably from that of the air. In general, the mean annual water temperature is slightly higher than the air temperature. The extent to which the temperature of lakes varies from the air temperature depends, primarily, upon their depth. In summer, the sun's rays with the aid of currents set up by waves, warm the water of deep lakes to depths of about 150 feet. Below this depth, however, the temperature remains substantially uniform, at a little above the mean annual air temperature, throughout the year. The temperature of the water near the bottom of deep lakes in northern latitudes usually remains very close to the temperature of maximum density.

The variation, with depth and season, of the temperature of Lake Geneva, Switzerland, and Lake Cochituate, Mass., is graphically shown in Fig. 149. Lake Cochituate freezes over, whereas Lake Geneva remains open the year around. After the entire body of water in the former lake has reached the temperature of maximum density, *i.e.*, 39.2° F., the surface water cools and, becoming lighter, remains at the surface until ice forms. With increasing cold, the ice temperature continues to drop and more and more of the layer of water immediately below the ice cover cools down to between 32 degrees and 39.2 degrees. From a few feet below the ice to the bottom of the lake the temperature remains at about the point of maximum density. As soon as the ice breaks up, in spring, the entire body of water soon attains uniform temperature, making it very susceptible to circulating currents set up by air movement over its surface. As the heat received from the sun increases, the surface water heats more rapidly than the deeper layers and, being lighter, remains at the top. The result is that by the end of mid-summer, the surface of the water usually has at least as high a temperature as the air.

During the season of falling temperature the water remains continually warmer than the air, because, as the surface water

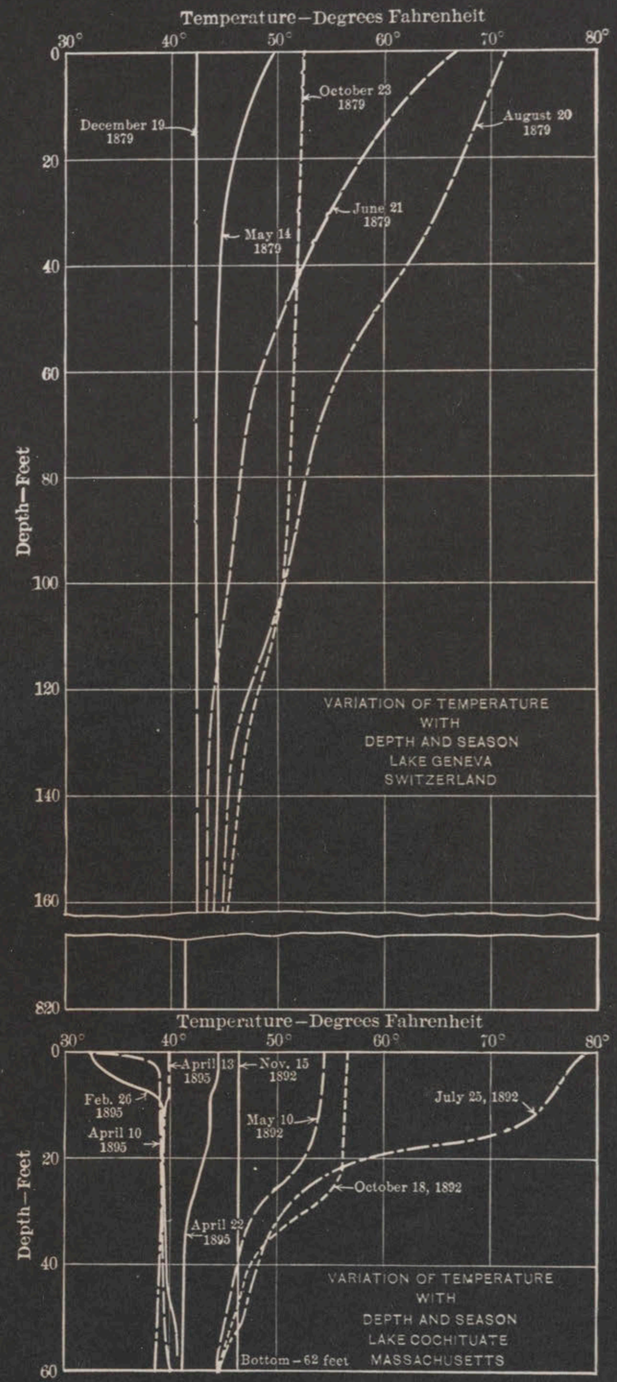
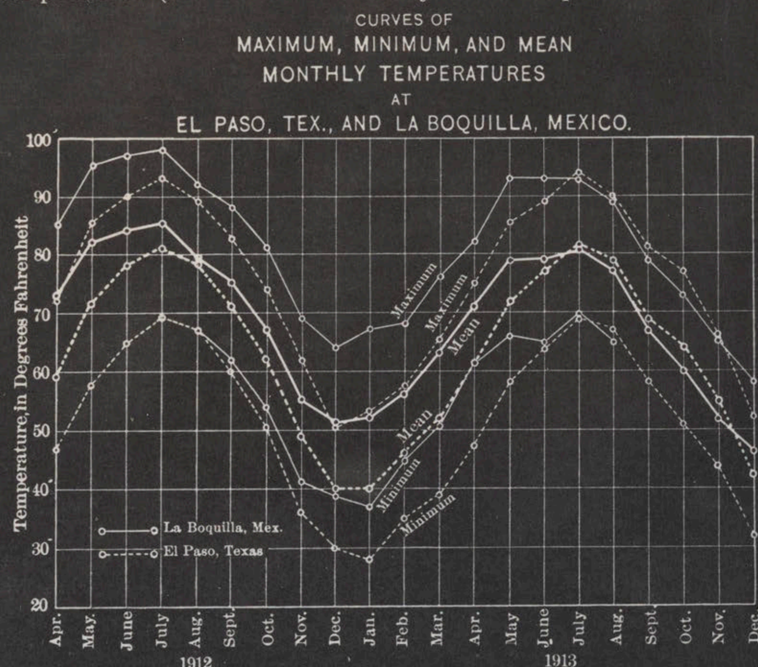


Fig. 149.

Ady

the monthly evaporation depths corresponding to all monthly mean temperatures at places on the Great Plateau in Texas and New Mexico having elevations of 4 320 ft.) it is assumed may be applied safely to Lake Conchos; also on the Great Plateau, but about 500 miles farther south, in Mexico.

In Table 37 and on Fig. 14 are given the observed monthly mean temperatures (the mean of the daily mean temperatures for each



Note:-Later data give the following additional monthly mean temperatures at La Boquilla

Jan. 1914-Max., 69°; Min., 55°; Mean, 62°.
Feb. 1914- " 73°; " 40°; " 56°.

The corresponding monthly mean temperatures at El Paso were

Jan. 1914-Max., 61°; Min., 35°; Mean, 48°.
Feb. 1914- " 61.5°; " 36.5°; " 49°.

FIG. 14.

month) at La Boquilla for 21 months, April, 1912, to December, 1913, inclusive. In Table 30 these twenty-one monthly mean temperatures are repeated (with that for January, 1914, added), and there are given also the twenty-two corresponding depths of monthly evaporation, as read off from Fig. 15.

From Table 30, the evaporation depth from 3-ft. square pans floating on Lake Conchos should have been 80.43 in. for the calendar year,

1913; but, for a composite year, made up by adding the mean evaporations for each of the 12 months, it would be 85.59 in., or 6.5% greater.

From the 22 months' record, however, it is practicable to make up eleven periods, of 12 consecutive months each, and so gain much more knowledge of the variations in yearly evaporation depth. This is done in Table 31.

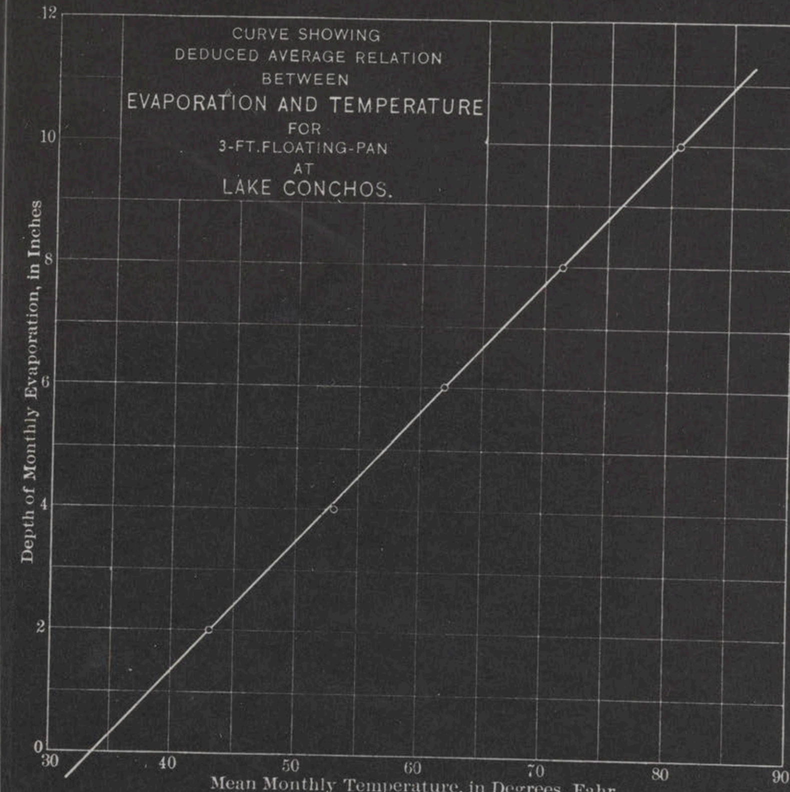


FIG. 15.

The variations in the evaporation depths for 12-month periods are shown better by Table 32.

It is believed that the most reliable and accurate value from Method *A* of the yearly evaporation depth from 3-ft. square pans floating on Lake Conchos is (so far as can be obtained from the data) 84.74 in.

By Subsidiary Conclusion (*c*), the yearly evaporation depth from a lake surface is only 62% of that from a 3-ft. square pan floating

Clay

cools, it becomes heavier and sinks and is replaced by warmer water from below. The circulation thus set up extends deeper and deeper. Cooling proceeds throughout a layer of increasing thickness, eventually reaching the bottom of the lake or at least to a depth of about 150 feet below the surface. If cooling continues after the entire body of water has reached the point of maximum density, the surface temperature is rapidly reduced and the lake freezes over.

The currents set up in spring and fall by the change in the temperature of relatively deep bodies of water are of considerable importance in connection with public water supplies on account of their effect on the character of the water.

The temperatures determining evaporation from the lake surface are, of course, the surface water temperatures, but these, it will be noted from what has been said above, are intimately related to the temperature of the entire body of water, and this depends largely upon its depth. The greater the depth of a lake the greater the excess of fall evaporation from its surface over spring evaporation, at the same temperature.

When reasonably complete records of both air and surface water temperatures, in addition to records of relative humidity and wind velocity are at hand, the evaporation from deep water can be computed directly from the observed data by means of the evaporation formula. Usually, however, no such observational data are available.

In order to meet the need for a measure of evaporation from relatively deep bodies of water, and applicable at least to average conditions, the author has constructed the curve of Fig. 150, on the basis of the available observational data and the known general relationship between air and water temperatures. This curve, of course, is intended merely to represent an average measure which may be applied when specific data are not available.

Fig. 151 shows the evaporation loss from the Lake of the Woods as observed by the Manitoba Hydrographic Survey

between 1913 and 1915.* This lake has an area of about 1500 square miles and is about 100 feet deep in places at its northern extremity, but only about 25 feet deep throughout the main

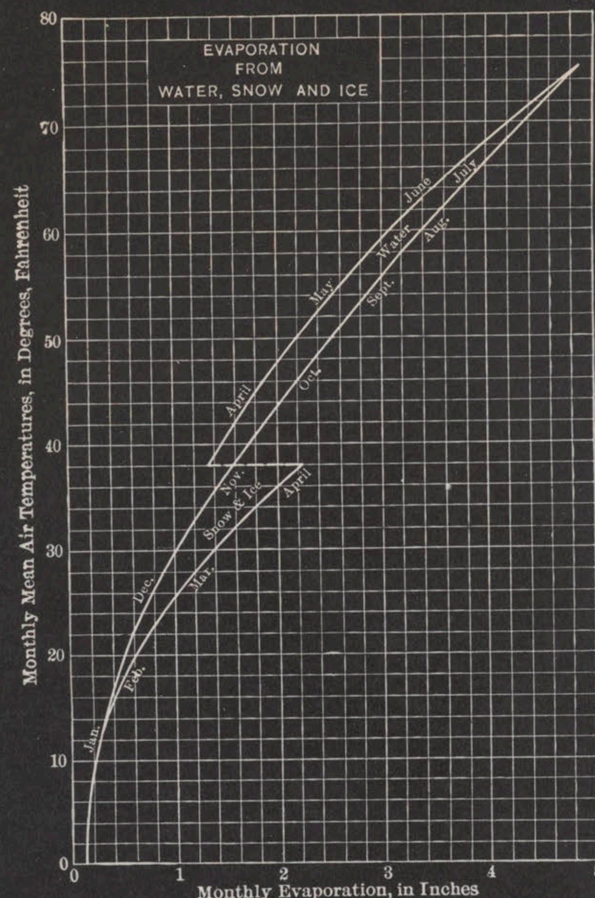


Fig. 150.

southern portion. The water temperature at the northern end, at Keewatin, Ontario, where the measurements were made, lagged considerably behind the air temperature, resulting in

* Observations continued to 1925 do not warrant any material modification of this curve although they indicate a possible shift to the left of about one-tenth inch evaporation.

[illegible]

After a careful study of Bigelow's work, the author has concluded to retain, for the present at least, the old Dalton formula.*

TABLE 19. — CORRECTION FOR SIZE OF EXPOSED EVAPORATION PANS

Size of pan	Relative evaporation		
	Grunsky	Bigelow	Sleight *
2 foot	1.87	1.82	1.30
3 "	1.56	....	1.25
4 "	1.43	1.44	1.19
6 "	1.30	1.24	1.11
Large water surface	1.00	1.00	1.00

* "Evaporation from the Surfaces of Water and River-bed Materials" by R. B. Sleight, Journal of Agricultural Research, July, 1917.

Correction for Size of Pan. — There does not appear to be any good reason for making a substantial reduction in evaporation from a large water surface as compared with evaporation from a pan floated in the same body of water, as proposed by Bigelow and others.† Differences between evaporation from large bodies of water and from evaporation pans may be ascribed, mainly, to differences in temperature as the result of the use of too shallow pans and the heating effects of the portion of the pan projecting above the water surface. When deep, fully immersed pans are used, comparable results are obtained. For pans entirely exposed above land or water surfaces, however, a correction should be made. Grunsky‡ has proposed a correction based mainly upon the relation between wetted perimeter and area of pan which agrees reasonably well with Bigelow's observations on exposed or partially immersed pans.

* A comprehensive paper on evaporation, together with extended discussions, appears in Trans. Am. Soc. C. E., 1916, pages 1829 to 2060.

† Charles H. Lee in Trans. Am. Soc. C. E., 1927, p. 340, shows that the temperature of the water in floating evaporation pans is substantially the same as that of the body of water in which the pan is floated.

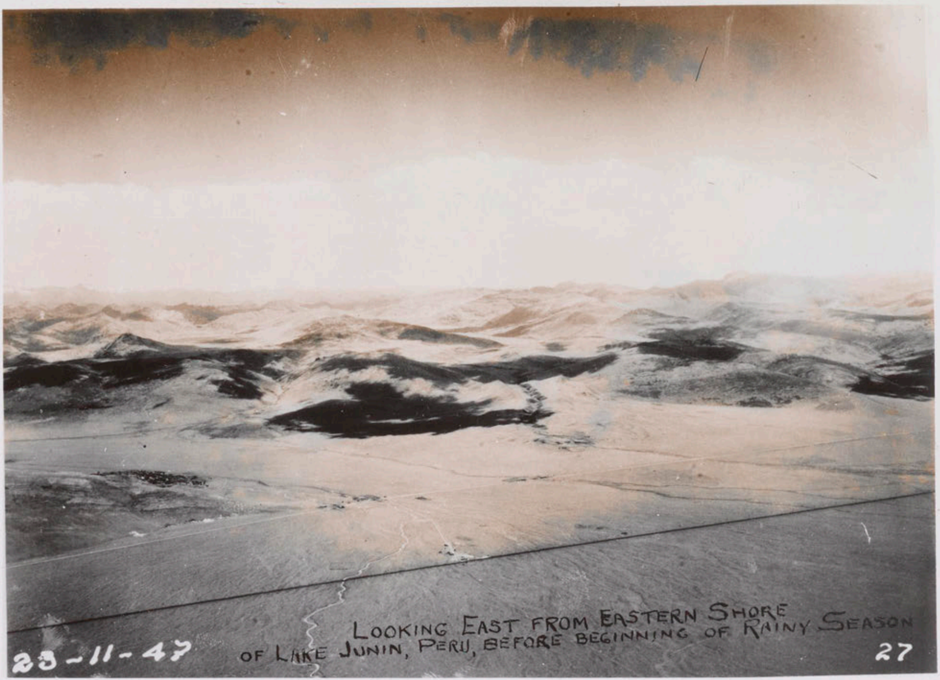
‡ Grunsky, C. E., Trans. Am. Soc. C. E., 1916, page 1970.

Methods of Measurement. — Measurements of the evaporation from pans of water set in the ground or floated from rafts in large bodies of water have been made in a considerable number of places in the United States and elsewhere. Both square and round pans have been used, although the preferable piece of apparatus would appear to be a strong circular pan, 3 feet in diameter and not less than 18 inches deep, with a sharp-pointed indicator in the center. A common mode of procedure, in measuring evaporation, is to add, each day, an amount of water equal to what evaporated during the previous 24-hour period. The water is usually added by cupfuls representing $\frac{1}{100}$ inch in depth over the surface of the evaporating pan, until the water level is again up to the top of the sharp-pointed index in the center of the pan. A rain gage placed nearby is used as a measure of the precipitation on the evaporation pan for which correction must be made. The use of a circular pan has the advantage of always giving the correct height of water even though the pan may not be level.

By far the best way of making an observational determination of evaporation from a large water surface is to use the floating pan, even though it is often difficult to prevent the splash of water both in and out of the pan as the result of wave action. The use of pans suspended above the water or placed in the soil nearby, usually involves still greater possibilities for error. Fine brass wire netting, coiled into a spiral and placed in the evaporation pan but not permitted to project above the water surface, has been found to produce a very satisfactory baffling effect. The evaporation pan should be bound with heavy straps of iron so as to prevent distortion, particularly at the base where the index is fastened, and should preferably be not less than 3 feet in diameter and not less than 18 inches deep, the water being maintained as high in the dish as wave action permits.

In determining the evaporating power of the atmosphere, botanists are making extensive use of porous-cup atmometers. One of the best types in use is that invented by B. E. Living-

[illegible]


LOOKING EAST FROM EASTERN SHORE OF LAKE JUNIN, PERU, BEFORE BEGINNING OF RAINY SEASON
23-11-47
27

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23-11-47
LOOKING EAST FROM EASTERN SHORE
OF LAKE JUNIN, PERU, BEFORE BEGINNING OF RAINY SEASON
27

Mr Addicks

January 26, 1948

Mr Gustave Reinberg, Vice Pres.,
Cerro de Pasco Copper Corp.,
40 Wall Street, New York City 5

Dear Mr Reinberg: **OROYA WATER SUPPLY**

In accorcance with recent correspondence I have visited the Navy Department in Washington and was permitted to peruse their files to date insofar as they have been "declassified" on the subject of the rainmaking experiments.

The Office of Naval Research has grown to be quite an institution, headed by an admiral responsible directly to the Secretary of Navy. The investigation inwhich we are interested is the Geo-Physics Branch in Charge of Commander Revelle. The man immediately in charge is Mr Earl G. Droessler. The group is housed in Bldg. T-3 adjoining the Navy Department. The field man is Lt-Commander Daniel F. Rex,USN.

Droessler was out of town but I had a long talk with Revelle (Dr Roger Revelle of the Scripps Institue of Oceanography at La Jolla, California, in the Navy the last 6 years but just out of uniform and looking for a successor when he will return to California). The set-up is a joint operation "CIRRUS" of the Army and the Navy,but apparently principally by the latter, with the General Electric Company under contract for technical direction. It has been decided to make the scientific part of the work available to the public but anything pertaining to its military applications is "SECRET". I enclose an off-set copy of the first progress report of the General Electric Company just issued by the Office of Technical Services, Department of Commerce. You can get as many copies as you want at $1.25 per. The second progress report will issue in the near future and a development of the mathematical theory involved in cloud precipitation will be published by Langmuir in one of the scientific societies transactions.

The work done is highly intelligent and quite impressive. The effects of a "seeding" spread very rapidly over an area of miles and the cost is insignificant.

Certain definite cloud characteristics are required but work now is inprogress to create these in clouds lacking them. The ideal is where a cloud the top of which is slightly below freezing is blown onto a mountainside creating an updraft. A smoke machine on the ground can deliver silver iodide particles into this draft and precipitation results. Silver iodide has a very low vapor pressure and remains in the desired state of subdivision a long time. It does not matter, in a case like Cerro's, where the snow- or rainfall occurs as long as it is within the desired watershed. The silver required is quite negligible. The General Electric Company is being inundated with requests for practical application and is also being threatened with lawsuits resulting from the apparently unsettled legal question as to whether the land title includes the overlying aircolumn as well as the subterranean rights.

As to bringing Peru into this picture, there is no objection to passing all this released information along to any individual as long as it is not made a formal delivery to the Peruvian Government as such. Even though the result is the same the law forbids handing a foreign government any military information. This is just protocol but it often matters just how a thing is handled. Revelle says that the Navy would welcome the appointment of a suitable Peruvian Naval officer under the existing officer exchange basis who would be made a member of the experimental team and learn the whole story. He says the naval attaché at the U. S. Limaembassy will know the whole procedure. I suggest that you have this explored without delay.

I think the whole matter should be evaluated without delay. It may be worth little to Cerro or it might prove very important in the matter of hydroelectric water supply and it requires no elaborate undertaking on our part.

Very truly yours,

Alex


23-11-47
LOOKING EAST FROM EASTERN SHORE
OF LAKE JUNIN, PERU, BEFORE BEGINNING OF RAINY SEASON
27

582

Adm. Bowen 3445
Flovez

Geo-physics branch

Adm Paul F Lee

Roger Revelle
Scripps

Gordon Lill

	LA	MMA
50 miles →		
22 -	4.50	—
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Papers	0.10	—
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Fees	0.40	1.25
Papers	0.20	—
Movie	—	0.88
Cab	0.50	—
Report	1.25	—
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25 - 0.50 0.25 0.50 0.15 3.60
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26 -

T3 - RM 2059

Ch. Revelle

ADDRESS REPLY TO
CHIEF OF NAVAL RESEARCH

WASHINGTON 25, D. C.
AND REFER TO:

NAVY DEPARTMENT
OFFICE OF NAVAL RESEARCH
WASHINGTON 25, D. C.

for PEACE OF MIND - BUY SAVINGS BONDS

EXOS:ONR:N428:EGD:oh

Serial Number: 21021

28 NOV 1947

Mr. Lawrence Addicks
Bellaire, Maryland

Dear Mr. Addicks:

Your letter of 6 November requesting a copy of the first quarterly progress report for Project CIRRUS has been received by this Office.

You are advised that this research is conducted under an Army contract with joint support from the Office of Naval Research. The distribution of the research reports, other than within the Naval establishment, is accomplished by the Meteorological Branch, Evans Signal Laboratory, Belmar, New Jersey.

Extra copies of this report are not available for distribution in this Office. Arrangements can be made for you to review a copy of the report if you will contact Mr. Earl G. Droessler, (phone, Republic 7400, extension 2060.)

Sincerely yours,

R. Revelle

R. Revelle
By Direction, Chief of Naval Research

Ackg

Lt Comm. Daniel F. Rex USN
Chairman, Operations Committee

Cerro de Pasco Copper Corporation

Cable Address:
Cerrocop-Lima.

P.O. Box 2412

Lima, Perú, December 10, 1947

ORIGINAL & FIRST CARBON AIR MAIL LETTER

CARBON BY STEAMER SAILING

Mr. Gustave Reinberg, Vice-President,
Cerro de Pasco Copper Corporation,
40 Wall Street,
New York, 5 N. Y.

Dear Gus:

The enclosed memorandum indicates how much Commander Roldan needs some help. I understand General Electric scientists developped this idea so perhaps some helpful data could be obtained from them. The Saturday Evening Post for October 25th has an article in it which might give some leads. As it is, the boys are just flying around using up gasoline and oil and getting nowhere.

Sincerely yours,

George.

GFT;tb
Encls.

December 5, 1947

To: Mr. George F. Train

From: M. Archimbaud.

Rainfall precipitation.

In compliance with your instructions the writer contacted on even date Commander Ernesto Roldan Seminario who, as Chief of the Metereological Investicgation Department of the Ministry of Aeronautics is in charge of the experiments being conducted by the Governement of Peru in order to ascertain the possibilities of producing rain over dry aereas.

Comm. Roldán--and the Peruvian authorities--are well cognizant of the fact that rainfall thorughout the year over the sierra region would be most beneficial not only to the sierra inhabitants and their agricultural aereas but to the coastal people as well, being that waters do eventually come down to the coast.

But, being that the experiments in question are in in the hands of government employees, who had never dealt with anything similar, they lack the necessary information for the most succesful goal of the experiments.

They are particularly interested in:

Methods used in ascertaining types of cloud-formations.

Temperatures which are most apt to produce useful cumulous formations. Seasons, in any, most favorable.

Results obtained in different climates and topographies

Equipment used for rain precipitation, and reasons for selection of same.

Availability of equipment.

Particular knowledge useful in such investigations or special studies that metereologists must undertake to better equip themselves for this type of work.

Best regions over which metereological observatories may be placed--and extent of obsservations

Comm. Roldán has on hand different publiactions that deal with the subject but has been unsuccesful in obtaining direct information from those people actually engaged in these experiments.

Thank you.

M. Archimbaud

FOR ______________________

LAWRENCE ADDICKS
BEL AIR
MARYLAND

COPY

A-104 November 6, 1947

Office of Naval Research,
Washington, D. C.

Gentlemen:

Is it possible to obtain a copy of the "first official report on Project Cirrus", quoted at some length in the current issue of "Science News Letter"?

I am interested in hydroelectric water storage in the Peruvian Andes (Cerro de Pasco Copper Corporation).

I use this old letterhead merely for purposes of identification.

Very truly yours,

Add

A-104 November 6, 1947

Office of Naval Research,
Washington, D. C.

Gentlemen:

Is it possible to obtain a copy of the "first official report on Project Cirrus", quoted at some length in the current issue of "Science News Letter"?

I am interested in hydroelectric water storage in the Peruvian Andes (Cerro de Pasco Copper Corporation).

I use this old letterhead merely for purposes of identification.

Very truly yours,

Adp

A-103 November 6, 1947

Mr Gustave Reinberg, Vice Pres.,
Cerro de Pasco Copper Corp.,
40 Wall Street, New York City 5

Dear Mr Reinberg: OROYA POWER SUPPLY

I enclose a clipping regarding the dry ice artificial weather tests. I have been watching these experiments with a good deal of interest, having in mind possible application to Cerro's water storage. I am asking for a copy of the full report, if available.

You will note that one of the projected aims is "man-induced snow and rainfall over mountain areas to fill reservoirs for irrigation and hydroelectric power". It would be very nice if Peru could be made one of the coöperating experimental areas in addition to "Alaska and northern Canada".

What do we know about cloud conditions preceding the breaking of the dry season?

Very truly yours,

Cdo

Memorandum
to
Mr. Reinberg

Water Storage

I have advanced two ideas for increasing dry season storage at Lake Junin.

The first was to anticipate the December rains by airplane "seeding" flights. This may have merit, and I am planning to keep informed as to progress on the Army-Navy-General Electric "Project Cirrus". To date we have no idea of the quantitative factors.

The second was to stop evaporation from Lake Junin during the dry season by applying a cover or oil. Complete success would supply 500 second-feet of additional water, using data in the Ehle report, equivalent to 8,000 KW additional throughout the dry season. Theoretically, only nominal quantities of oil would be required, but I have dropped the idea without pursuing further the practical factors involved because an adequate oil cover would not only stop evaporation but prevent oxygenation of the water and kill all animal and vegetable life dependent thereon, creating social problems very inadvisable in the present state of unrest.

Lawrence Addicks

LA/ij

12-9-47

A-113 December 18, 1947

Mr Gustave Reinberg, Vice Pres.,
Cerro de Pasco Copper Corp.,
40 Wall Street, New York City 5

Dear Mr Reinberg: OROYA WATER SUPPLY

I have your letter of the 16th with enclosed letter from Mr Train and shall have a try at it in due course. Probably not much to be done until the Xmas holiday is out of the way.

Very truly yours,

Ralp

CERRO DE PASCO COPPER CORPORATION
40 WALL STREET, NEW YORK 5, N. Y.

December 16, 1947

Mr. Lawrence Addicks
Bel Air
Maryland

Dear Mr. Addicks:

We are sending you herewith a letter just received from Mr. Train with its enclosed memorandum about the progress of the artificial rain experiments in Peru. You have probably noticed that there was an article in the current issue of Time magazine also.

Mr. Train's remarks confirm the impression I received in Peru about this work, and, if it is possible for you to arrange with either the General Electric Company or the Navy Department, or both, to give the Peruvian Government any assistance in this matter, I am sure it will be appreciated.

Sincerely yours,

Gustave Reinberg

Gustave Reinberg

GR/ij
Encls.

METEOROLOGY

Water Can Make Rain Fall

Common cumulus clouds of any temperature will precipitate in a "chain reaction rainfall" when sprinkled with water.

➤ WATER, of all things, can be used to make rain fall. This latest and ironic development in rain-making was reported in a communication to the National Academy of Sciences by Dr. Irving Langmuir, associate director of the General Electric Company's Research Laboratory.

He advanced the theory that a little water dispensed on the right kind of cloud at the right time under the right conditions would start what the scientist termed a "chain reaction rainfall." Water, instead of the dry-ice or silver iodide used in earlier experiments, would trigger rain from common cumulus clouds, a type of heaped up white cloud found over the South and Pacific coast regions throughout the year and over the Northeast commonly in the summer.

"Theoretically," Dr. Langmuir told fellow scientists, "a single drop of water, if dispensed in the right spot, would be sufficient to cause the chain reaction rainfall."

Unlike the dry-ice experiments, water could set off precipitation from cumulus clouds of any temperature. In order to produce rain with water on a cumulus cloud, the cloud must have a vertical, upward current of at least five miles per hour, contain fully-grown water droplets, a high water content and a thickness of several thousand feet.

Under the new theory, the falling water particles would grow as they fell through the cloud until they reached a critical size of about three-sixteenths of an inch. After that, the particles would shed smaller bits of water which would be carried back into the cloud until they grew big enough to fall.

Dr. Langmuir said he believes this type of rain-making has already been achieved. He developed the new theory from reports of unexplained rain in some of the dry-ice experiments. In some cases, he explained, ordinary ice particles on the dry-ice probably melted to set off rain under conditions where dry-ice alone should not have produced any precipitation.

Science News Letter, December 20, 1947

EXPERIMENTO SOBRE LLUVIA ARTIFICIAL

En las primeras horas de la tarde de ayer se iniciaron los experimentos sobre lluvia artificial, portando un avión, de la sección de "Transportes Militares", una cantidad de hielo seco y la otra máquina al Ministro de Agricultura, ingeniero don Pedro Venturo.

PARTE EL PRIMER AVION

Del campo militar de Limatambo partió el primer avión —perteneciente al 31 Escuadrén de la Escuela— piloteado por el Capitán del C.A.P. señor Fernández, transportando al Jefe del Portafolio de Agricultura.

Minutos después se elevó la segunda máquina en que viajaron el Comandante Ernesto Roldán Seminario —Director del Servicio Meteorológico del Ministerio de Aeronáutica del Perú— en compañía del Alférez Jorge Barboza.

DATOS EXTRAOFICIALES

Hemos sido informados que los aviones, en su vuelo hacia el interior, encontraron cúmulos en diversos puntos de su itinerario y el piloteado por el Comandante Roldán y el Alférez Barboza realizó experiencias sobre la humedad de las zonas y la altura de ciertas regiones.

NO FUNCIONO EL APARATO

El aparato que para pulverizar el "hielo seco" sobre las nubes que produce la lluvia artificial —que se nos afirma ha sido fabricado en el Perú— no funcionó como se esperaba. La baja temperatura del producto lo obturó.

Sabemos que hoy —según las conferencias realizadas por los Ministros de Aeronáutica y el de Agricultura y con los señores Buonanni y el ingeniero Flores León— volverá a intentarse tan interesante experiencia.

AGUA PARA LAS TIERRAS SECAS DEL PERU

CUANDO el doctor Irving Langmuir, ganador este año del premio Nobel de Ciencia, anunció hace muy pocos días la posibilidad de provocar lluvia artificialmente y transformar en menos de un lustro la economía de zonas áridas, el Perú debió sentir la alusión muy en lo vivo. Para hacer esta alusión más directa, el propio sabio mencionó a la costa del Perú, al Norte de Chile y a los desiertos de California, como zonas actualmente estériles que podrían ser transformadas en emporios de riqueza agrícola.

La nota que el Ministerio de Agricultura acaba de publicar anunciando que se practican desde hace algún tiempo experimentos para provocar lluvias en la costa peruana, mediante el uso del llamado hielo seco, concentra más intensamente el interés sobre este asunto. Es un episodio enteramente nuevo de la lucha del hombre contra la Naturaleza que, en este caso concreto, afecta de un modo directo e inmediato al porvenir del Perú. El buen éxito de los experimentos significaría, en lo que uno alcanza a atisbar desde ahora, la corrección de uno de los errores que la Naturaleza ha cometido con este país, al distribuir tan irracionalmente el agua, de forma que, mientras en una zona es una necesidad angustiosa, en otra se convierte en un problema incontenible.

Desigualdades tan irritantes como ésta hay en la mayor parte de las sabias disposiciones de la Naturaleza, cuya sabiduría tal vez debamos estimar, no por lo ajustado que estén sus designios a los nuestros, sino por lo que tienen de estimulante, de aleccionador y de incitación las adversidades que nos ocasiona con sus errores. La arbitraria distribución de las aguas ha incitado siempre a los pueblos de tierras secas a idear medios ingeniosos para remojar su suelo y hacerlo cultivable. Los antiguos moradores del Perú demostraron una sorprendente inventiva para llevar el agua hasta lugares que parecían inverosímiles. Sobre todo, que parecían asombrosos a los sucesivos ediles de las municipalidades de Lima y del Rimac, que nunca han tenido el coraje de abordar la empresa de irrigar el cerro San Cristóbal para hacer de él un motivo decorativo digno del paisaje de la ciudad.

Los árabes, gente de suelo seco, idearon y construyeron también eficaces sistemas de irrigación, que todavía desafían al tiempo y al progreso en la región levantina de España, y supongo que en otros lugares de la cuenca del Mediterráneo. Pero no siempre los gobiernos o los pueblos han afrontado los problemas planteados por la necesidad de irrigación. Han dejado transcurrir el tiempo, sin encarar el gasto, fabuloso, pero remunerador, de embalses, captaciones, canalizaciones y túneles. He oído muchas veces decir aquí que la irrigación de Olmos hubiera sido la salvación agrícola del Perú y, sin suficientes elementos de juicio para saber si esto es o no cierto, ahora me inclino a considerar canceladas todas las culpas de negligencia o demora. Si alguna vez puede estar justificada la economía de lo que no se hizo, esta vez es ahora, puesto que será muchio más barato esperar a que el hielo seco o el sistema del doctor Langmuir nos impida el trabajo y el gasto de las obras hidráulicas.

A falta de uno, serán dos ahora los sistemas para hacer llover. Uno el que se está experimentando aquí, el llamado de "hielo seco". El otro es el que podríamos llamar de "agua mojada", que el doctor Langmuir llama de "reacción en cadena". O sea, explicado de la manera tosca que puede hacerlo un profano: el sistema de "mojar" las nubes con agua. De tal modo que una gota, empapando a otra, llega a resolver en agua toda una nube. Cualquiera de los dos sistemas o el del voduro de plata, con tal de tener éxito, van a plantearnos un problema gramatical de alguna importancia. Todos hemos aprendido que "llover" es un verbo impersonal, porque no podíamos decir "llueve yo" o "llueves tú"; pero no tardaremos en poder decir "llueve él", refiriéndonos al sabio norteamericano o a nuestro Ministro de Agricultura, aunque, con respecto a éste, la expresión es más bien la de "mandar llover", frase que se usa en España para significar que alguien se excede en su autoridad hasta más allá de sus atribuciones.

Esto de "mandar llover", que en el futuro podrá ser un poder casi discrecional de un jefe de sección, fué otrora un privilegio exclusivo de santos varones. Tenemos a Moises que, con su incontenible vara de los prodigios, hizo brotar el agua de la peña del Monte Oreb. Y, más adelante, nos encontramos con el profeta Elías que, en competencia con un ejército de sacerdotes de Baal, hace bajar del cielo una llama espontánea que consume una res y provoca desde el Monte Carmelo una lluvia que pone fin a una terrible y larga sequía que asolaba Samaria.

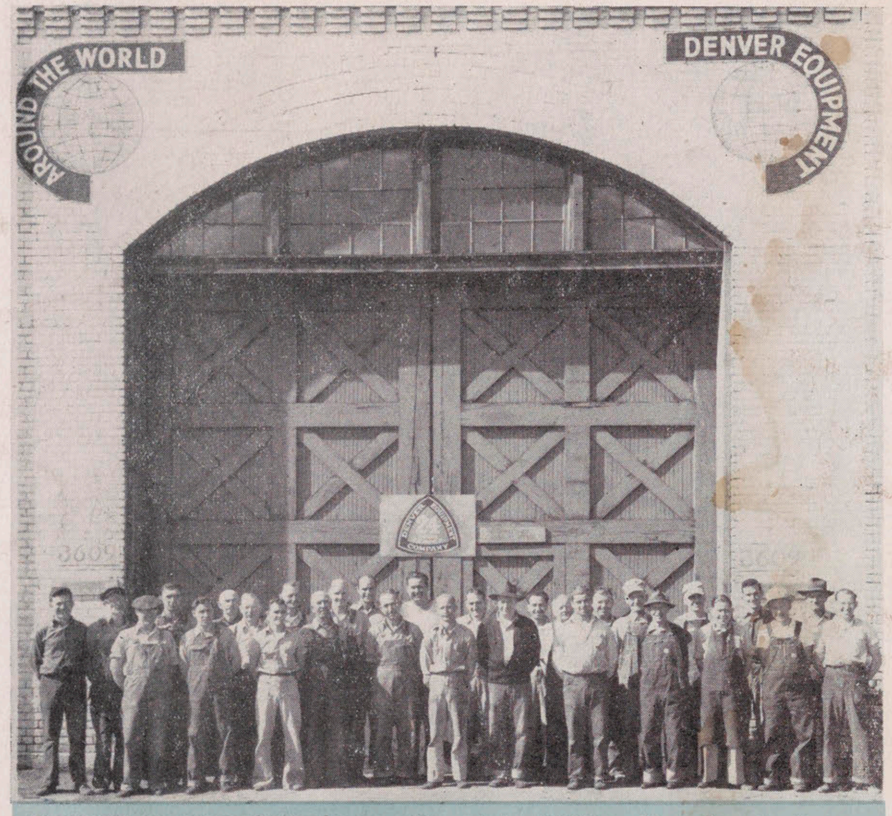
Después hemos sabido de los embaucadores que fingían hacer llover y sacaban "el agua" a los crédulos granjeros del Oeste norteamericano con sus ritos y supercherías pseudocientíficas. Ellos se limitaban a hacer uso —o, mejor dicho abuso— de los datos que el Departamento de Meteorología de la nación ponía al servicio de todo el mundo. O sea: que aparecían cuando iba a concluir una sequía, y ellos "hacían llover" cuando ya estaba dispuesto por la Providencia y previsto por la Ciencia.

Más tarde, hace casi diez años, el argentino Baigorri se erigió en el taumaturgo de las aguas pluviales y dijo que haría llover en Buenos Aires. Pero me parece recordar que aún estaba en los preparativos cuando comenzó prematuramente —al menos con arreglo a los cálculos de Baigorri— una temporada de lluvias que echaron a perder el experimento.

En la campiña castellana he visto hace muchos años que los labriegos disparaban potentes cohetes contra las acumulaciones de nubes tormentosas. Como espectáculo no dejaba nada que desear, y a los muchachos que nos reuníamos a contemplarlo nos divertía tanto, que no comprendíamos por qué estaban tan angustiados los campesinos en la posibilidad de que un pedrisco les pulverizase la cosecha. En honor a la verdad puedo decir que, positivamente, llovía poco después de las detonaciones. También he llegado a pensar que los labriegos tenían que darse prisa a emplazar y disparar sus baterías antes que la tormenta reventase por su propia iniciativa. De modo que queda la duda sobre cuál era la causa y cuál el efecto, y de si aquel derroche de pólvora en salvas era la lucha contra la tormenta o una estrepitosa colaboración con ella.

Los nuevos horizontes —horizontes que son toda una paradoja meteorológica, puesto que son a la vez despejados y nubosos— nos ofrecen la posibilidad de lluvias "a la carta", o tal vez "al telegrama". Lo cual quiere decir que lloverá en el momento en que haga falta para sazonar una cosecha o preparar el campo para una siembra. Hay que esperar —o al menos hay que desearlo— que los "llovedores" tengan el poder de limitar la dosis, de tal forma que no nos veamos como el aprendiz de brujo, que sabía el sortilegio para hacer brotar agua en el caldero, pero que ignoraba cómo contener la efusión del líquido cuando se desbordaba de la olla e invadía la habitación. La posibilidad de un nuevo Diluvio Universal de cuarenta días y cuarenta noches, mientras los técnicos buscan el medio de cerrar el grifo no es halagadora. Sin embargo, bien podemos afrontarla. Por lo que a mí respecta, soy de un lugar de la tierra donde he visto llover durante cincuenta y dos días, y el problema allí es el de saber cómo podría impedirse que llueva tanto. Si se llegase a una inteligente regulación pluvial, podríamos esperar que el desierto del Sahara llevase una parte de las aguas de la cuenca Amazónica, lo cual no es absolutamente disparatado, al menos a mi juicio, si se considera que no hay más que una cantidad constante de agua y que la que caiga en un sitio no cae en otro, de la misma forma que las lágrimas vienen a mermarse de otras secreciones.

Sea por el "hielo seco" o sea por el "agua mojada", podemos esperar que dentro de tres o cuatro años haya papas y camotes a un precio razonable, aunque, al paso que llevamos, no se puede prever lo que se considerará razonable entonces en materia de precios de tubérculos y de otros productos alimenticios.



These men are among those who assemble and ship DECO machines from the Denver Equipment Company shops in Denver. Many of these men are old timers who have been with the company since its earliest days. Their loyalty and industry have contributed much to the quality of DECO machines, serving around the world.

MAN MADE SNOW

(Continued from page 3)

use of the process by causing clouds to release their moisture high in the mountains, instead of in the valleys, so that the water can be stored in reservoirs for generating hydro-electric power. It can also be stored for irrigation purposes or used on ski slopes when needed.

During the terrible forest fires which ravaged New England this fall, artificial precipitation was used as a natural overhead sprinkling system with satisfying results. It is believed that hail storms may be avoided by seeding large storm clouds.

Some other methods for causing artificial precipitation are also being developed. One system uses silver iodide particles as artificial nuclei for the formation of snow crystals. Experiments with a rapid expansion of air theory have been made in the laboratory. Scientists found that by exploding a balloon, or shooting off a pop-gun into a supercooled cloud, snow crystals will develop. Neither of the above are as practical or as easily executed as the dry ice method.

Another method which may prove to be even better than the dry ice method for producing rain only is being developed. With this new method ordinary water is dispersed into cumulus clouds, not supercooled, and rain is induced directly, by a "chain reaction." This process should be very beneficial in the summer months when supercooled clouds are scarce.

Weathermaking may never become so exact that we will no longer be caught in an unexpected blizzard; or so simple that we can throw away our garden hoses. But we will be able to manipulate the weather to our advantage in the years to come, and may lessen, if not prevent, some of Nature's more destructive forces. Perhaps this is the long awaited answer to the prayers of both ancient and modern peoples.

OPERATING NOTES

(Continued from page 4)

precipitation circuit, which in our case is a Merrill-Crowe plant. The cyanide consumption is not excessive, being 0.5 lbs. NaCN per ton compared with 0.32 lbs. per ton for current slime.

Lime consumption is high being 12 lbs. unslaked lime (with a CaO content of 85%) per ton treated.

The average original value of the slime is 1.740 dwts. with a residue value of 0.232 dwts. Recovery being 1.508 dwts. giving a theoretical extraction of 86.7%.

The result is comparatively good with that class of material.

Value of gold recovered per ton	12/6
Total working costs per ton	3/8
Net Profit per ton treated	8/10

ANSWER TO TEST YOUR WITS PROBLEM ON PAGE 13:

Joe's brother
Peter — Harry
Charlie — Joe
George

SNOW MAID

Inspired by newspaper accounts of artificial snow making, 17 year old Kathleen Roan decided to try it herself. Scientists were amazed at her results.

By placing one wash tub inside of another, and filling the space between with crushed ice and rock salt, a refrigeration unit was formed. When the temperature dropped to 31° F, she breathed into the tub, producing a supercooled cloud. Kathleen then seeded this cloud with pellets of dry ice, and tiny, sparkling snow crystals appeared.

—Courtesy G. E. News Bulletin

MAN MADE SNOW

If you're hoping for a white Christmas this year, and the weather man disappoints you . . . don't despair . . . for with a plane (if you have one handy), some dry ice, and the right kind of a cloud, you can create a blizzard all your own.

The idea of man actually causing precipitation is an age old dream come true. From ages past, peoples have tried by rituals and prayers to their gods, to bring down rain. This was certainly neither a scientific nor a sure approach to the problem. So, except for a great deal of loud lamenting, we have accepted what Mother Nature has offered . . . when she has offered it. But, at last science has developed a solution.

Successful precipitation experiments, most of them by dropping dry ice into supercooled clouds, have been conducted in many sections of the country. An enterprising farm community in Oklahoma, had 105 pounds of dry ice dropped into a cloud 13,500 feet above the ground to try and bring down some much needed rain for their crops. They got results all right, and things would have been wonderful, if a strong wind had not then appeared. The rain was welcomed by a town 19 miles away . . . which goes to show that Nature still will play a pretty important role in man's planning.

Making rain is not the only benefit to be gained from man's new knowledge. By the overseeding of clouds with dry ice, precipitation can be prevented. The cloud becomes over frozen, and the resulting snow crystals are so small and light that instead of falling to the earth, they merely float about in the atmosphere. In this way, large and damaging storms may be prevented.

In 1943 the Army Air Forces asked the General Electric Laboratories to search out the cause of ice formation on plane wings, a condition which was sending many planes and their crews to destruction. A detailed study of these icing clouds was made, and the knowledge gained led to the discovery of artificial snow.

Vincent J. Schaefer was one of the leaders of the investigation. In July of 1946 he created a miniature snowstorm in his laboratory by breathing into a cold chamber, thereby producing an icing cloud. After dropping in powdered dry ice, snow crystals appeared. The first of a series of successful attempts to produce snow from real clouds took place near Schenectady, New York, in November of 1946.

Creating a snowstorm cannot be done in just any cloud that happens to be drifting by. Nature must furnish certain specifications. The cloud must be an icing cloud, in a so-called supercooled condition. Such clouds remain in a liquid state at as low a temperature as —35° C. All that is necessary to transform these clouds into millions of tiny ice particles, or snow, is a very sudden drop in temperature. This drop can be brought about by the dispersion, or seeding, of crushed, dry ice into the cloud.

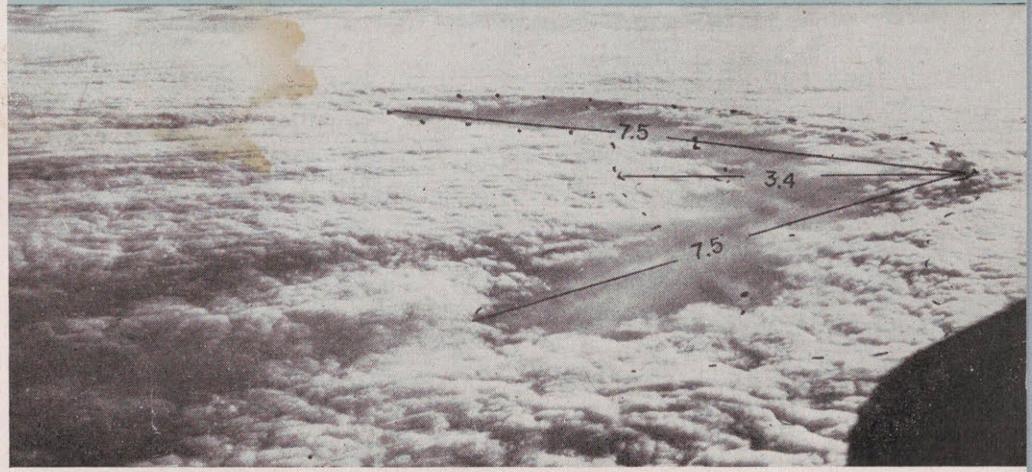
These dry ice particles should be at a temperature of about —78.5° C. for best seeding results. As the dry ice pellets drop into the warmer atmosphere of the cloud, sublimation occurs. The resulting vapor spreads into the cloud, and since it is so much cooler than the surrounding air, the cloud cools very rapidly. The water vapor in the cloud then freezes into tiny ice nuclei, about 10^{-6} cm. in diameter. As these ice particles fall through the cloud, more vapor freezes on them, and soon the whole cloud is transformed into falling snow.

No matter what changes the drops undergo they always leave the cloud as snow. If the air through which this snow must fall to reach the earth is below freezing, it will complete its course as snow. But if the air is above freezing, and contains enough humidity, the snow crystals will melt and fall as rain. Insufficient humidity will cause the evaporation of the drops before they reach the ground.

Farm communities are not the only groups who may benefit from this useful new development. Switzerland hopes to make

(Continued on page 14)

The scaled section in this supercooled cloud was produced by seeding an L-shaped area totaling about 11 miles, with only 25 pounds of dry ice. Thirty minutes later (when this photograph was taken) the precipitating area had become 15 miles long and 3 miles wide.
—Courtesy General Electric Company



OPERATING NOTES ★ ★ ★

REPULPING DRIED SLIMES WITH A DENVER SUPER-AGITATOR AND CONDITIONER

D. Dowling, Reduction Officer

D. Dowling

The following notes are on the adaptation of the Denver Super-Agitator and Conditioner to the treatment of an old slime dam situated on the Village Main Reef Gold Mining Company property, Johannesburg, South Africa.

We were confronted with the problem of how to get this solid packed slime, laid down more than 50 years ago, and now containing 14% moisture, back into an emulsion with about 50% moisture. This was to be accomplished without having to regrind the material and without the use of settlement tanks. Grinding was unnecessary, in any case, as test gradings showed 95% minus 200 mesh material.

We considered the possibility of using brick makers puddling machines but discarded that idea for several reasons. We then decided to use a 12'x12' Denver Super-Agitator and Conditioner, which we had on an adjacent property, and which was not then in use. We consulted the Denver representatives here in Johannesburg as to the feasability of the idea, and they concurred with our scheme and thought it was a practicable proposition.

We laid the plant down and results were very much better than our most sanguine hopes. The plant consists of the conditioner, an 18" conveyor belt from ground level to top of tank, with necessary driving gear, and a 3" sludge-pump to pump the slime to the actual treatment tank. The slime is dug out from the face of the slime dam by native labour, shovelled into one ton trucks, and trammed to a small receiving bin, from which the feed is conveyed into the Denver Super-Agitator and Conditioner.

Unfortunately a waste rock dump was superimposed on the slime dam in the distant past, and this rather complicated matters. In some places the overburden of loose rock is as much as 8 feet. Notwithstanding the care taken to remove the rock, stray pieces find their way into the conditioner tank, much to the resentment of the propellor. (Cast steel propellors are better than cast iron in this case.)

We experienced a few teething troubles, chief of which was that the 6" feed pipe, which delivered the slime to the stand pipe, was too small in diameter to take the large sized slime lumps. We installed an 8" pipe, and no further trouble was experienced.

Water is added to the feed pipe to give a resultant emulsion of approximately 51% moisture. Added to the entrapped air drawn down the feed pipe by the suction of the propellor, is air from four jets spaced around the the bottom of the tank to prevent settlement at the edges of the tank. They keep the slime in movement, and nearer to the churning action of the propellor. The speed of the propellor shaft is 150 RPM. Thirty H.P. is required to operate the whole plant.

Starting with 12" of water above propellor level, slime and water are fed to the tank until it is filled, when the slime emulsion is pumped away to a treatment tank. The Denver Super-Agitator and Conditioner is filled and emptied four times in the 8 hour shift, giving an output of 60 tons per shift. This figure could be improved upon with the addition of extra native labour.

It will be readily understood that after 50 years in situ the slime will be highly acid due to the decomposition of the iron pyrites, forming the ferrous compounds FeS and $Fe(OH)_2$, which have a very deleterious effect on cyanide treatment. Lime is added to the conditioner to combat the acidity, and as before mentioned, air is blown through the slime converting the ferrous compounds to the innocuous ferric state. The alkaline content of the slime is maintained at .024% $Ca(OH)_2$.

Lead nitrate (10 lbs. per charge of 60 tons) is added at the treatment tank to precipitate soluble sulphides, after which the cyanide is introduced, to make up an initial strength of .026% NaCN. Treatment is continued for 8 hours in a second agitator, after which the slime is discharged through a filter.

The slime is treated separately from the current mill product but the gold bearing solution from the filter joins the common

(Continued on page 14)

Compacted material from a 50-year-old slime dam is being conveyed to the Denver Super-Agitator and Conditioner shown at the extreme right. Raising the moisture content from 14% to 50% was effectively and economically accomplished in this Denver machine.

METALS AT WORK

CHROMIUM ALLOY

A new advance has been made in the field of mirrors—mirrors that you can see through from one side, but which reflect as do ordinary mirrors on the other side.

The reason you can't see through an ordinary mirror from the back is because it is chemically silvered and then covered with an opaque backing to keep the silver from tarnishing and rubbing off. Since transparent mirrors must both transmit and reflect light simultaneously, no such backing can be applied to them. Instead, they are surfaced on the reflecting side, by a "molecular bombardment" process with a chromium alloy, through thermal evaporation in a high vacuum. This alloy adheres so well that scrubbing or extreme temperature changes will not deteriorate the metal surface.

The chrome film on the glass is only four ten-millionths of an inch thick. (It would take 11,000 such thicknesses to equal the thickness of one sheet of newspaper.) Hence, light passes through, and photographs can be taken from the reverse side.

The uses of this amazing mirror are many and valuable. Used on front doors the "magic mirror" enables the housewife to ignore undesirable peddlers. The mirrors aid in cutting down apartment house crimes in large cities. Their use in observation in behavior clinics and psychiatric wards will be priceless. As "security" windows in banks, stores, and other such establishments their value will also be great.

—Courtesy Libbey-Owens-Ford Company

Test your WITS

FIND JOE'S BROTHER

Six men sat down to a game of poker at a circular table. Peter dealt the cards.

Harry sat next to Joe's brother and opposite Charlie. The man who sat to Charlie's left sat opposite Joe.

Joe's brother sat opposite the man who sat next to the man who sat opposite the man to Joe's right. The man who sat to the right of the man who sat next to the man who sat opposite Joe is George.

Can you place all the men in their proper places around the table and locate the correct position of Joe's brother?

(Answer on page 14)

COVER . . . ANGEL OF SHAVANO

(Continued from page 2)

the valley below. She even became grateful to Jupiter for her sentence. One year a drought devastated the crops of her beloved people. Her sorrow for them was so great that she began to cry. As the tears flowed, her body melted, ran into the valley, and supplied life-giving water to the people. Though she had lost her body, she was happy in the knowledge that she had saved her people.

So it is that each spring the Angel of Shavano melts and flows into the Arkansas River.

—*Photo by Henry R. Hay*

During a drought in the Southland, an old Negro preacher called his congregation to the church to pray for rain.

"Your faith is mighty slim," he stated sadly. "Here we have gathered to ask the good Lawd to make it rain, an' not a one of you brought an umbrella."

Froth Column

"Does that help, mister?"

☆

The demure young bride, her face a mask of winsome innocence, slowly walked down the aisle clinging to her father's arm.

As she reached the platform before the altar, her dainty foot brushed a potted flower, upsetting it. She looked at the dirt gravely, then raised her childlike eyes to the Minister and said, "That's a hell of a place to put a lily!"

☆

"Mummy," asked the little girl just returned from Sunday School, where the lesson had been on palaces in the sky. "Mummy, do they have skyscrapers in Heaven?"

"No darling. They have to have engineers to build skyscrapers."

☆

Fellows who drive with one hand are usually headed for a church aisle. Some will walk down it; others will be carried in a box. Either way, it's better to use both hands.

☆

A baby rabbit had been pestering its mother all day. Finally the exasperated parent replied: "You were pulled out of a magicians hat—now stop asking questions."

☆

"So your husband is one of the big guns in industry."

"Yes, he's been fired seven times."

☆

Once upon a time there was a boy penguin and a girl penguin who met at the Equator. After a brief but charming interlude, the boy penguin went north, to the North Pole; the girl penguin went south, to the South Pole.

Later on, a telegram arrived at the North Pole, stating simply: "Come quick—I am with Byrd."

REPUBLICA DEL PERU
MINISTERIO DE FOMENTO
DIRECCION DE MINAS Y PETROLEO

INSTITUTO GEOLOGICO DEL PERU

BOLETIN 4

BIBLIOGRAFIA CLIMATOLOGICA DEL PERU

por
ANGEL J. INDACOCHEA G.

LIMA, 1946

REPUBLICA DEL PERU
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ABREVIATURAS USADAS

Arch. Asoc. Per. p. el Prog. de la Ciencia = Archivo de la Asociación Peruana por el Progreso de la Ciencia.

Ann. Hydrog. = Annalen Hydrographie.

Ann. der Hydrogr. und marit. Meteor = Annalen der Hydrographie und Maritimen Meteorologie.

Ann. of the Astron. Observ. Harvard College = Annals of the Astronomic Observatory Harvard College.

Aufl. = Auflage.

Bol. Agr. y Ganad. = Boletín de la Dirección de Agricultura y Ganadería.

Bol. Aguas e Irrig. = Boletín de Aguas e Irrigación. Ministerio de Fomento.

Bol. C. Ings. Mins. Ags. = Boletín del Cuerpo de Ingenieros de Minas y Aguas del Perú.

Bol. Cia. Administ. del Guano = Boletín de la Compañía Administradora del Guano.

Bol. Direc. Fom. = Boletín de la Dirección de Fomento.

Bol. Esc. Ings. = Boletín de la Escuela de Ingenieros.

Bol. Min. Inds. y Constr. = Boletín de Minas, Industrias y Construcciones de la Escuela de Ingenieros.

Bol. Minist. Agricult. = Boletín del Ministerio de Agricultura.

Bol. Ofic. Min. y Petrol. = Boletín Oficial de Minas y Petróleo.

Bol. Soc. Geogr. de Lima = Boletín de la Sociedad Geográfica de Lima.

Bol. Soc. Geolog. del Perú = Boletín de la Sociedad Geológica del Perú.

Bol. Soc. Ings. del Perú = Boletín de la Sociedad de Ingenieros del Perú.

Bull. Amer. Geogr. Soc. N. Y. = Bulletin of the American Geographycal Society New York.

Bull. of Amer. Paleontology = Bulletin of American Paleontology.

Cap. = Capítulo.

Coord. = Coordenadas.

Cuad. Obs. Meterológicas = Cuadro de Observaciones Metoreológicas.

Cuad. Obs. Pluv. = Cuadro de Observaciones Pluviométricas.

Ed. Hamburg. = Editorial Hamburgo.

Fas. = Fascículo.

Festchr. = Festschrift

Gac. Cient. = Gaceta Científica.

Geogr. Rev. = Geographical Review.

Id. = Idem.

Imp. = Imprenta.

Inf. y Mem. = Informaciones y Memorias (Boletín de la Sociedad de Ingenieros).

Inv. y Progr. = Investigaciones y Progreso.

La Gac. Med. = La Gaceta Médica.

Lat. = Latitud.

Long. = Longitud.

Mem. d'Arceuil. — Paris. = Memorias d'Arceuil. — Paris.

Mem. Cons. Ocean. Ib–Amer. = Memorias del Consejo Oceánografico Ibero–Americano. Madrid.

Obs. Meteor. Facult. Ciencias = Observatorio Meteorológico de la Facultad de Ciencias Universidad Mayor de San Marcos.

Obs. Meteor. Municip. = Observatorio Meteorológico Municipal.

Obs. Meteor. Ofic. = Observatorio Meteorológico Oficial.

Obs. Meteor. Unanue = Observatorio Meteorológico Unanue.

Observ. Meteor. = Observaciones Meteorológicas.

Petermanns Geogr. Mitt. = Petermanns Geographische Mitteilungen.

Pg. = Página

pp. = de página a página.

Proc. Roy. Geogr. Soc. London = Proceedings of the Royal Geographical Society of London.

Ref. = Referencia.

Rev. Acad. Colomb. C. Ex. F. y Nat. = Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales.

Rev. de la U. S. M. = Revista de la Universidad de San Marcos.

Rev. de la U. de Arequipa = Revista de la Universidad de Arequipa.

Rev. de la U. del Cuzco = Revista de la Universidad del Cuzco.

Rev. de la U. de Trujillo = Revista de la Universidad de Trujillo.

Ser. Meteor. Nac. = Servicio Meteorológico Nacional.

Soc. Cient. = Sociedad Científica.

Secc. = Sección

Tm. = Tomo.

Trad. = Traducción.

Trans Amer, Geoph. Union = Transactions of the American Geophysical Union; Washington , D. C.

Vol. = Volumen.

Zeitchr. Oesterr. Ges. f. Meteorologie = Zeitschrift der Oesterreichischen Gesellschaft für Meterologie

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ON THE COVER

OUR cover picture is a bird's-eye view of the dam in the high Andes that is described in our first article. The structure was built by the Cerro de Pasco Copper Corporation to supply hydro-electric power for its extensive ore-reduction works at Oroya, a short distance away.

•

IN THIS ISSUE

FACED with the problem of building, at a conservative cost, a serviceable power dam in a narrow gorge the bottom of which is composed of glacial drift 140 feet thick, the engineers adopted a type of rock-fill structure that they had designed and successfully constructed some years previously in California. To prevent water from flowing underneath the dam, a concrete cut-off wall was extended down to bedrock and notched into the canyon side walls. The heel of the main structure rests on top of this wall into which is keyed a concrete apron that is on the upstream face of the dam and that forms a water seal for it. Precautions taken against the serious cracking of this apron as a result of any movement of the dam have thus far proved to be very effective; and there is now less leakage through the structure than when it was first placed in service. For the information embodied in our description of this dam and the illustrations included with it, we are indebted to Sanderson & Porter, the engineering firm responsible for the design.

•

THE *J. W. Van Dyke*, the first of three new Atlantic Refining Company oil tankers, is described in our second article. The power plant of this ship was engineered along lines that have not previously been applied to marine practice in this country. In view of the high efficiencies the vessel has thus far shown, it seems reasonable to predict that the pioneering done by Chief Engineer Goldsmith and his staff will have considerable bearing upon the design of future tankers.

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IN RECENT years we have published several articles dealing with the development of the modern rock drill. Another one is presented this month, and in it will be found not only some additional historical data but also facts that emphasize the important contribution the modern rock drill makes to industrial and social progress.

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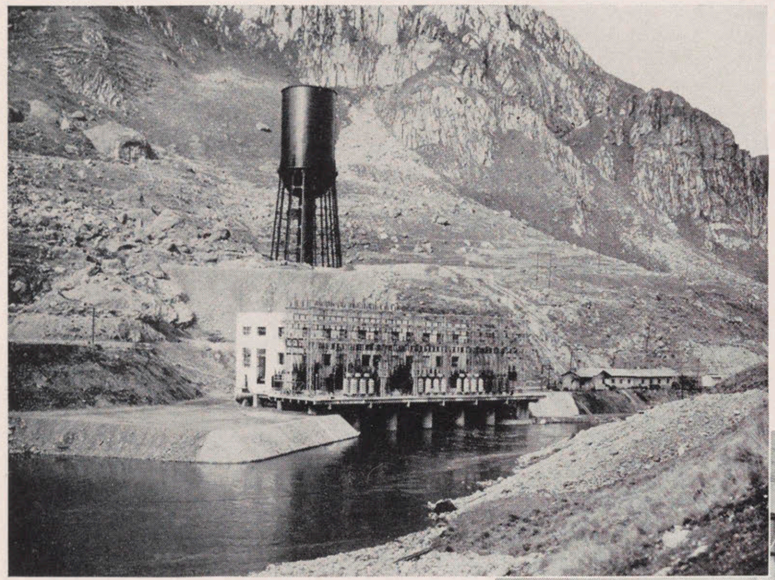
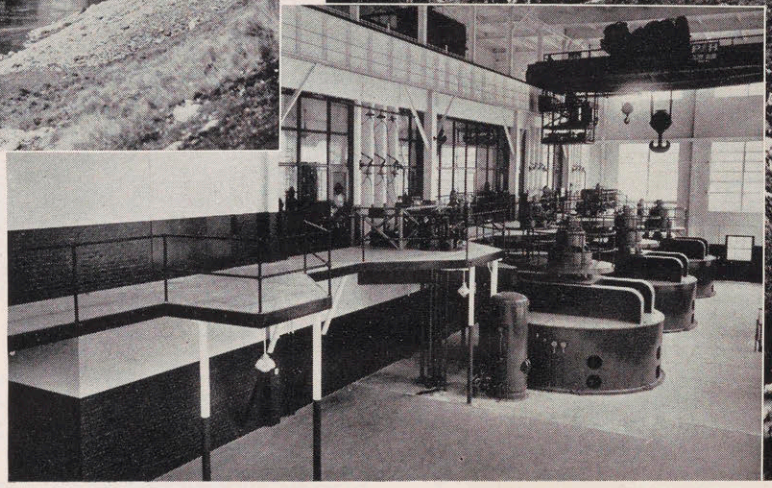
A Peruvian Dam of Unusual Design

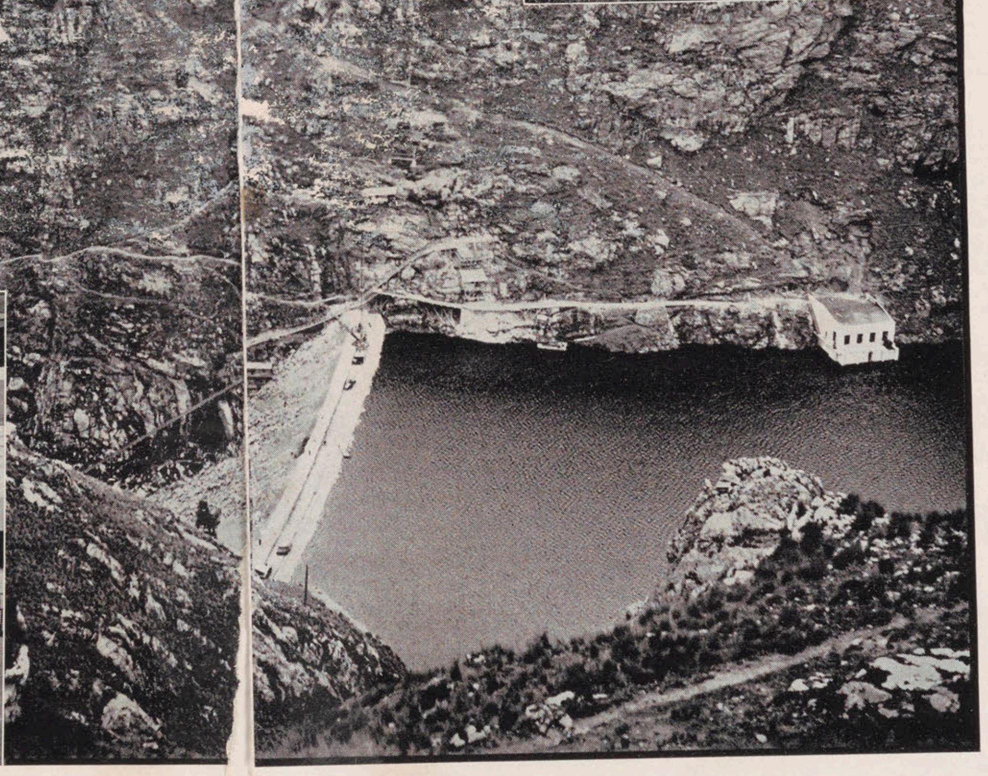
Allen S. Park

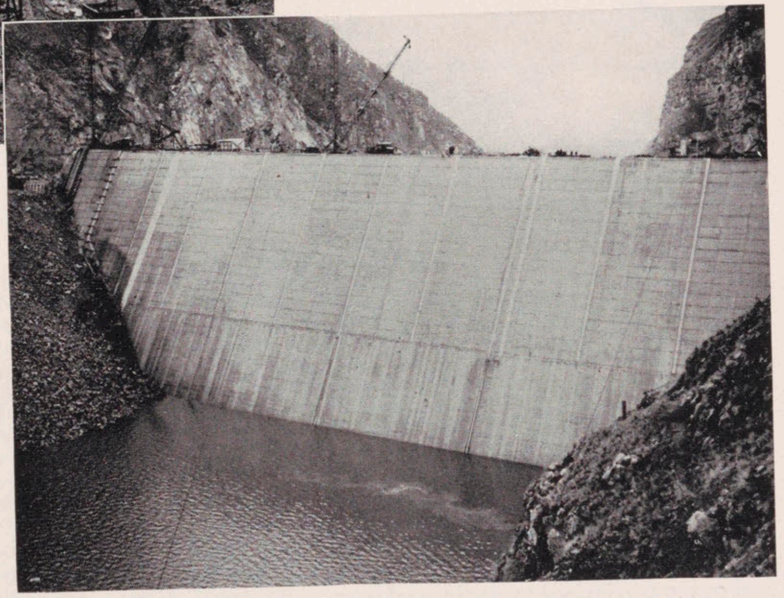




THE POWER HOUSE

Above is an exterior view of the generating station, with the differential surge tank in the background. The interior view (right) shows the three 17,000-kva. generators at present set up. Water for the operation of this plant is conveyed 7,500 feet from Malpaso Canyon Dam by tunnel, and reaches the turbines through penstocks 8½ feet in diameter. Provision has been made for adding a fourth unit when it is needed.





GENERAL VIEWS OF DAM

The dam, with the water behind it at full-pool level, is shown at the left. The white structure near the right-hand edge is the gatehouse for controlling the admission of water to the power tunnel. At the upper left are seen the power house and the surge tank, which are approximately 1½ miles distant from the dam. Above is the reservoir basin after it started to fill with water. The vertical contraction joints in the concrete apron are plainly visible. At the left, above, is a view of the downstream face. The canyon wall projects from the right-hand side almost to the center of the picture; and the spillway, which has been paved since this photograph was taken, extends down the rock face.

A HIGH, rock-fill dam of unusual design is one of the features of a hydro-electric power project recently completed in Peru by the Cerro de Pasco Copper Corporation. It is located on the Mantaro River, a tributary of the Amazon, and about 15 miles upstream from the Town of Oroya where much of the power will be used. The dam site is a narrow gorge, called Malpaso Canyon, through which the river flowed at El. 12,515 between walls of porphyry rock intruded in the sedimentary formation that predominates at the surface in that general area.

The gorge is at least partially of glacial origin, and is filled to a depth of approximately 150 feet with bowlders, gravel, and sand. At the dam site it is about 175 feet wide at the former level of the river and narrows to a bottom width of approximately 40 feet. It would have been too costly to excavate all the material that would have had to be removed to rest a dam of conventional design on bedrock. Accordingly, there was designed a rock-fill dam the heel of which is supported by a solid-concrete cut-off wall extending from El. 12,470 down to bedrock and the body of which rests on the yielding material of the river bed. The cut-off wall is 105 feet high, and the dam proper rises an additional 255 feet, making an over-all height of 360 feet from bedrock to the dam crest. The length of the dam at the crest is 497 feet.

From the dam, a power tunnel, about 7,500 feet long, delivers water to the power house, the tailrace of which is at El. 12,452. At the lower end of this tunnel are four penstock take-offs of which three are in use while the fourth is held in reserve for future development. Each of the three generating units now in service consists of a vertical-shaft water wheel with a rated capacity of 17,500 hp. when operating at 257 rpm. under a net head of 240 feet, and is direct connected to a 17,000-kva. generator with all accessories for governing the wheels and controlling and measuring the electrical output. Current is developed at 11,000 volts and stepped up to 50,000 volts for transmission.

The Mantaro River's tributaries rise on the eastern slope of the highest ridge of the Andes Mountains in Central Peru. Within its drainage area is Lake Junin, which lies at an altitude of 13,420 feet and has a surface area at normal level of 147 square miles. As a part of the undertaking, there was reared on the Mantaro a low dam—called Upamayo Dam—by means of which water can be diverted into Lake Junin during high-flow periods and then released during dry periods to flow down the river to the Malpaso Canyon Dam. In this manner the upper 10 feet of the lake's water is controlled and its surface elevation made to fluctuate with the season between El. 13,410 and 13,420.

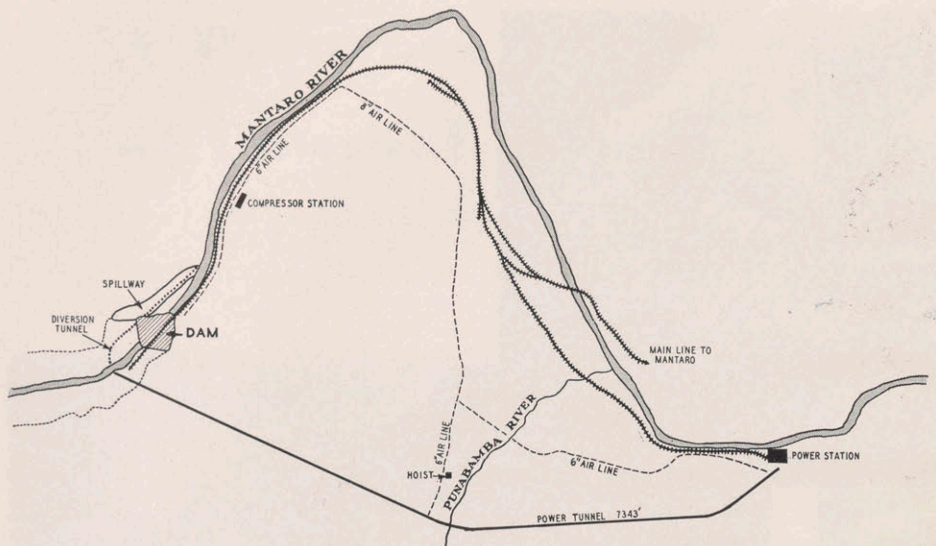
The upstream section of the Malpaso Canyon Dam consists of derrick-laid rocks and tapers from a bottom thickness of 150 feet to a top thickness of 12 feet. The upstream face has a slope of 1 horizontal to 2 vertical, and the downstream face has a slight batter of about 1 in 20. On the upstream face is a rubble-masonry wall which is laid in portland-cement mortar and ranges in thickness from about 6 feet at the bottom to 3 or 4 feet at the top. This facing is made of large, selected rocks some of which extend into the dry wall, thus bonding the two sections together. Against the upstream face of the rubble wall is laid a reinforced-concrete apron which serves as a water seal.

The downstream section of the dam is composed of dumped rock. This has a uniform downstream slope of 1½ horizontal to 1 vertical, with a surcharge of material, or source of supply, at the top that will serve to compensate for the expected settlement. This surcharge is 10 feet wide at the top and varies in height from 5 feet at the axis of the dam to 2 feet at the ends. In addition, waste rock from the excavation for the spillway channel was used to load the toe of the dam and also the natural bed of the river to a point 400 feet downstream from the toe.

In order to increase bearing and contact areas, to lessen settlement, and to add to the weight of the derrick-laid upstream wall, the spaces between large rocks were hand chinked with smaller rocks and quarry spalls, after which river gravel and sand were washed into the remaining interstices by streams of water 1½ inches in diameter and having a nozzle velocity of more than 100 feet a second. In placing large rocks with derricks, care was taken to get a good bearing of bedding surfaces and good end contacts with large rocks already in position before doing any chinking or washing in of gravel. The native workmen employed were very skillful in this type of dry-wall construction. They are descendants of the ancient Incas, whose ability along this line is evidenced by the remains of many fine structures in Peru.

Material for the dam was obtained from a quarry on the left bank of the gorge. The dumped section was started by placing a line of material across the canyon from wall to wall, and was continued by dumping rock down both slopes from the top of this fill. The upstream face formed a V with the downstream face of the derrick-laid wall. As the two sections were built simultaneously, it was possible to keep the bottom of this V-shaped pocket 5 to 10 feet below the top of the derrick-laid wall and thus develop considerable upstream thrust against the downstream face of the latter section before the water load was brought to bear against it from the other side.

Only sound quarry rock was placed in the dumped-fill section, and all material from seams was wasted. As in the case of the



GENERAL LAYOUT

This development is located in Central Peru and roughly east of Lima, on the eastern side of the Andes. It supplies some of the electric power for the operation of the Cerro de Pasco Copper Corporation's reduction works at Oroya, approximately 15 miles down the Mantaro River. The power tunnel has a cross-sectional area equivalent to a circle 18.4 feet in diameter, except for 473 feet at its lower end where there is a 17-foot-diameter, riveted steel pipe from which four 8½-foot-diameter penstocks lead to the power house. The Punabamba River crosses the tunnel line and headings were then opened in both directions.

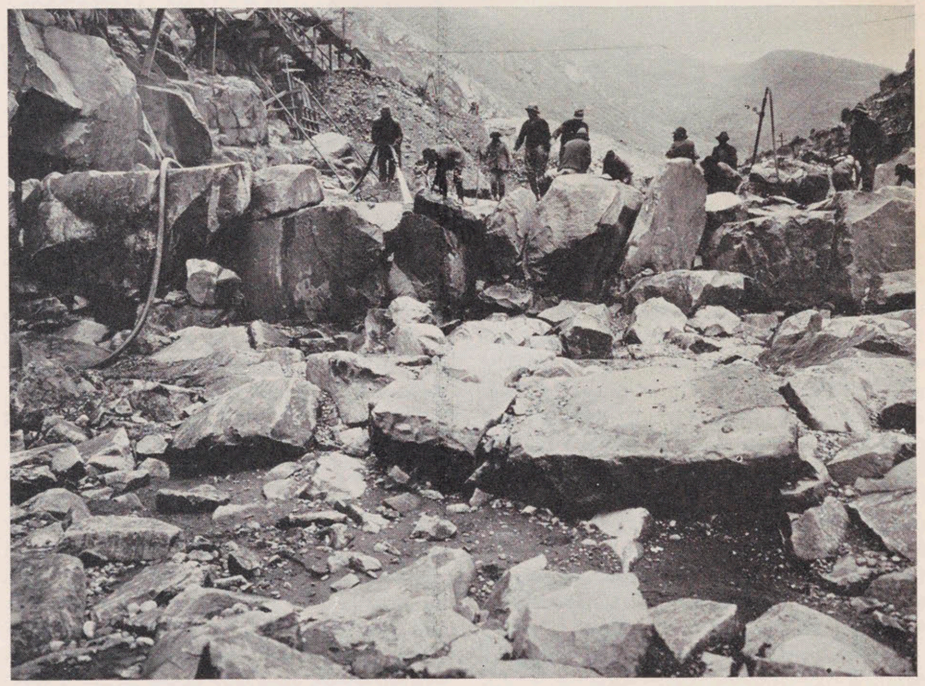
derrick-laid section, voids were filled with gravel and quarry fines by streams of water, and care was exercised to obtain good bearing contacts of the larger pieces of rock before this was done. Also, as provided in the specifications, the faces of the quarry rock were washed clean of fine materials before more was dumped on them. The gravel and sand used for filling voids came from a river deposit, about 3 miles downstream, that was also the source of the aggregates for all the concrete required on the job. These fines consisted of hard, sound particles, and were washed free of clay, loam, and silt before being delivered to the dam.

The purpose of the concrete cut-off wall is, of course, to prevent water from flowing through the unconsolidated material on which the dam rests at a velocity great enough to remove or disturb any of it. To accomplish this, the cut-off is notched into sound rock across the bottom of the gorge and up both sides from bottom to top. In addition, the foundation as well as the abutment rock was grouted by means of pipes carried upward through the concrete. These pipes were inserted in previously drilled holes, and grout was not introduced until the cut-off wall had risen high enough to insure adequate penetration under the desired pressure. The holes in the bottom were vertical and averaged 8 feet in depth. Those in the side walls were at an angle of 45° and from 12 to 17 feet deep.

In order to build this wall, it was necessary to excavate a trench 150 feet deep the full width of the gorge through the mixed material of the river bed. The initial 70 feet of the excavating was in open cut, but from that point on down to the bottom of the trench digging was continued between steel-sheet-pile retaining walls. As the material penetrated was highly pervious, suitable provisions had to be made for diverting the river, for keeping the seepage water down to a volume that would permit the excavating and concrete pouring to be done efficiently, and for the disposal of the water that entered the trench.

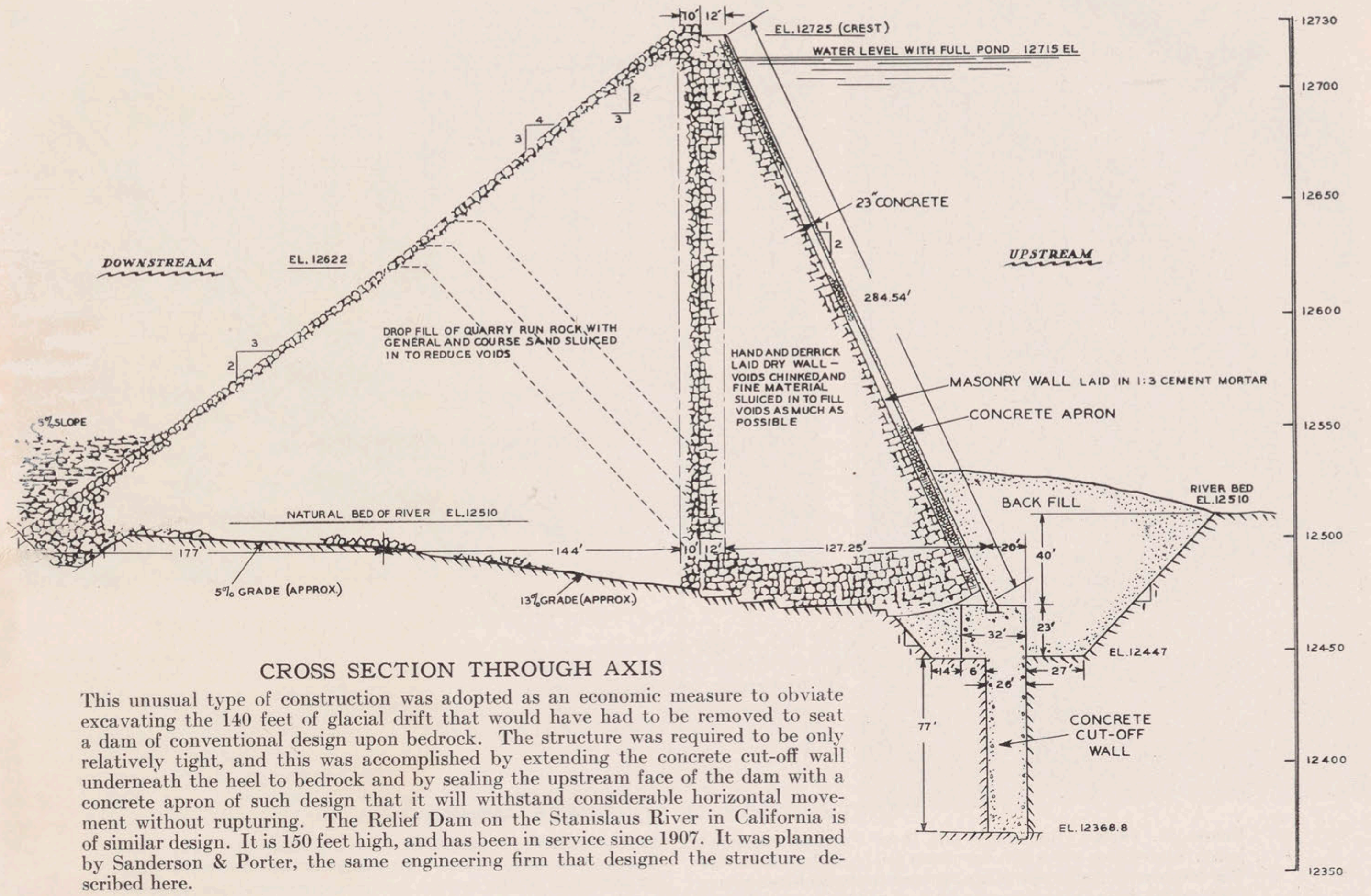
Construction work was started in 1929; and the industrial outlook at that time was such that it was deemed desirable to push operations with all possible speed to make additional electrical power available for the smelting and refining plants at Oroya. The building of the power house and driving of the power tunnel were undertaken first, the plan being to use the latter as a means of diverting the river during the rearing of the dam. To expedite progress on the dam, however, it was decided to drive a shorter tunnel, for diversion purposes only, around the dam site. This was begun in 1929 and finished in 1930. If the coming of the depression could have been foreseen, this work would not have been done, for all construction activities were suspended in 1931 and not resumed until 1934. But in the meanwhile, the power house, tunnel, and Upamayo Dam had been completed, and some work preliminary to the building of the Malpaso Dam had been done.

For diverting the river, a dam was constructed of timber cribs filled with rock and having a wall of steel sheet piling driven along its upper face to a depth of 15 feet. This structure was located about 50 feet downstream from the portals of the diversion tunnels and about 300 feet upstream from the trench for the cut-off wall. The water surface behind the diversion dam was 165 feet higher than the bottom of the trench. This head, along with the nearness of the dam to the trench and the loose character of the intervening ground, made the problem of keeping excessive quantities of water out of the trench a serious one. To lessen the porosity of the river-bed material, it was decided to inject hot asphalt—which is liquid when placed and solid when cold—into the ground where the diversion dam was to rise. Its introduction was expected to plug the larger openings and to reduce the size of the smaller ones by compressing the material.



WASHING FINES INTO VOIDS

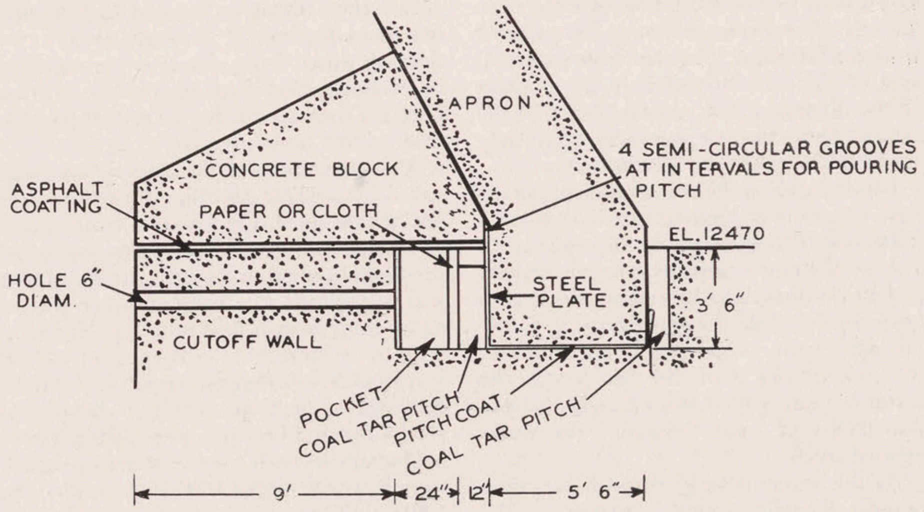
A view of the derrick-laid section, showing a high-pressure water jet in use washing clean sand and gravel into spaces between large rocks. These were laid with care to obtain good bearing and end contacts. Any large spaces remaining were chinked before washing in the fine material.



CROSS SECTION THROUGH AXIS

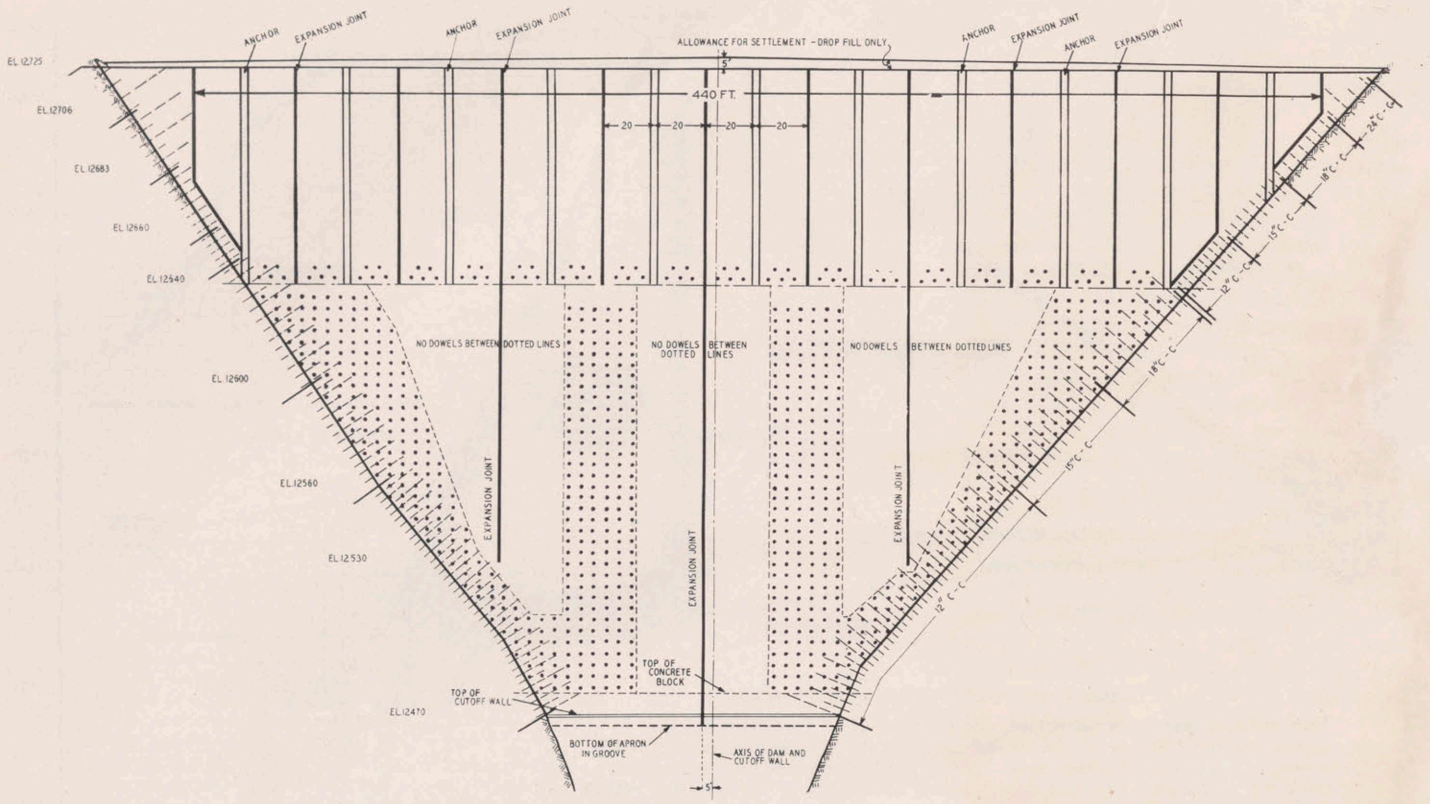
This unusual type of construction was adopted as an economic measure to obviate excavating the 140 feet of glacial drift that would have had to be removed to seat a dam of conventional design upon bedrock. The structure was required to be only relatively tight, and this was accomplished by extending the concrete cut-off wall underneath the heel to bedrock and by sealing the upstream face of the dam with a concrete apron of such design that it will withstand considerable horizontal movement without rupturing. The Relief Dam on the Stanislaus River in California is of similar design. It is 150 feet high, and has been in service since 1907. It was planned by Sanderson & Porter, the same engineering firm that designed the structure described here.

The American Asphalt Grouting Company of Chattanooga, Tenn., was employed to do this work, and sent down the necessary equipment and materials and an experienced man to direct the operations. A line of 3-inch pipes, spaced 7 feet apart, was put down to ledge rock across the canyon at the dam site. In each casing there was placed a 1½-inch pipe perforated with ¾-inch holes at 6-inch intervals for 20 feet from the bottom. This pipe was run down to ledge rock, and the casing was then withdrawn partway so that the pipe was unshielded up to the point where the perforations ended. A stopper to fill the annular space between the 1½- and 3-inch pipes was next put in position and forced down to the foot of the casing. Hot liquid asphalt pumped through the 1½-inch pipes issued from the openings and was thus forced through the gorge fill. The pumping pressures ranged from 20 to 600 pounds per square inch. The asphalt was kept hot by passing an electric current through an iron wire that was threaded into the inner pipe to the bottom of which it was connected but from which it was otherwise insulated. When a hole took a comparatively large amount of asphalt under low pressure, it was assumed that the material was going beyond the limits within which grouting was to be confined. Under such conditions the current was switched off and the asphalt allowed to cool, after which the current was turned on again and pumping resumed when the asphalt in the pipe had reached the desired temperature.



DETAILS OF APRON BASE

The base of the concrete apron on the upstream face of the dam rests in a groove in the top of the cut-off wall. To allow the apron to move horizontally in case of settlement of the dam, spaces were left between it and the sides of the groove, both upstream and downstream. Coal-tar pitch was placed in these; and in the concrete on the downstream side are pockets into which the pitch will be forced if enough pressure is applied. Leading from these pockets and through the concrete of the cut-off wall are ducts through which the pitch can be extruded.



CONSTRUCTION OF CONCRETE APRON

Below El. 12,640, the apron has three vertical expansion joints: above that elevation the joints are at 40-foot intervals. The lower part of the apron is anchored to its rubble-masonry backing by dowel pins spaced on 5-foot centers and indicated on the drawing by dots. In the upper section, each 40-foot-wide strip of concrete is anchored by a block of concrete, 4 feet wide and 3 feet deep, along its vertical center line. This is seated in a groove in the rubble-masonry wall. Each strip and its anchor block were placed in one continuous pour. At each side of the apron, 1-inch-square steel bars anchored in the rock of the canyon wall extend alternately 7½ and 15 feet into the concrete. Only every third bar is shown in this drawing. The figures along the right-hand edge refer to their spacing.

Following the asphalt-grouting, the diversion dam was constructed, and in a further effort to reduce seepage, a clay blanket was spread on the river bed above it for a distance of 100 feet or more. These measures served to lessen the flow of water into the cut-off-wall trench to an average of around 700 gpm. As the cross-sectional area of the fill material just downstream of the diversion dam covers about 19,500 square feet, the seepage averaged only about 0.036 gpm. per square foot.

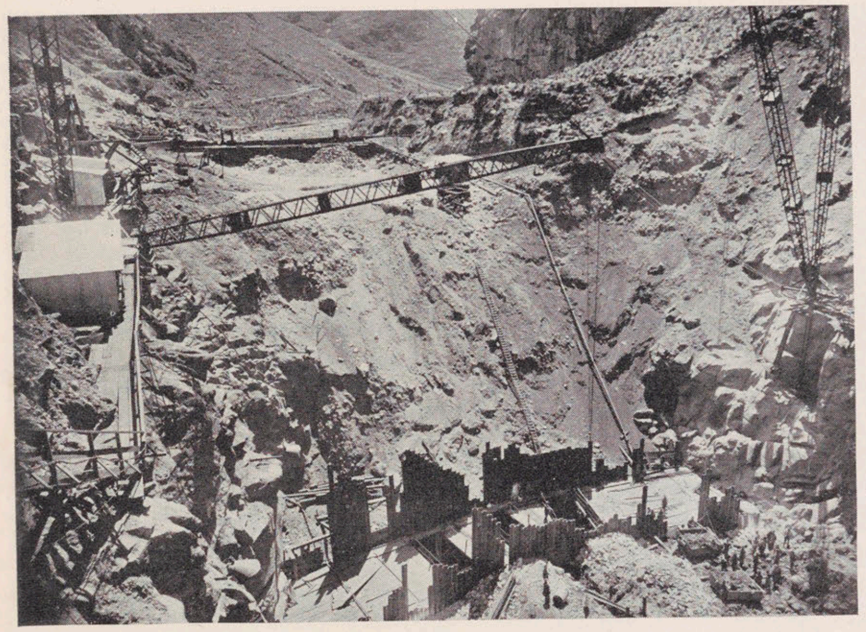
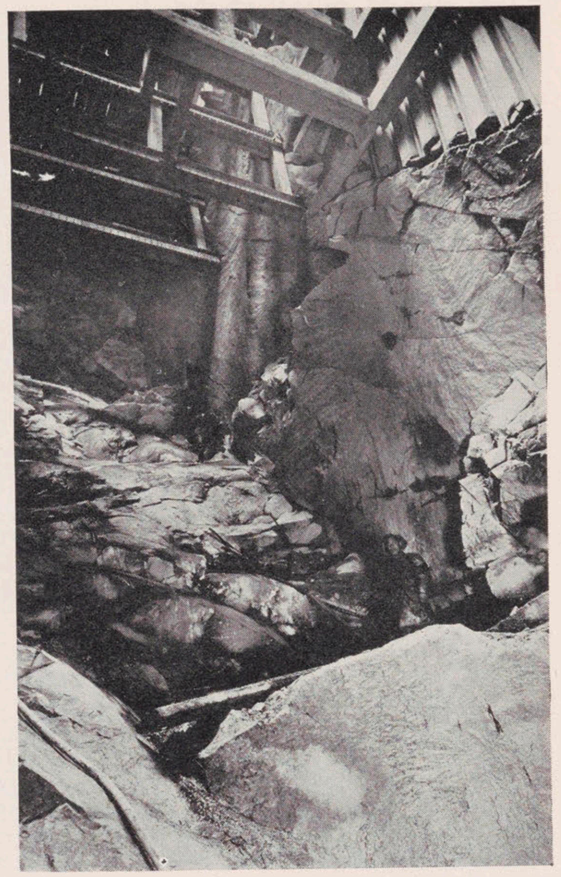
For dewatering the cut-off trench, pumps were placed in a sump at the bottom of a shaft sunk through rock on the right bank a short distance upstream from the trench. A drift draining into this sump was driven from a point near the shaft bottom to the far side of the gorge. As holes drilled in the roof of this drift did not permit the water to drain into it fast enough, the roof was blown off, and thereafter the water entered freely.

As the water flowing through the temporary diversion tunnel returned to the river channel about 1,000 feet downstream from the cut-off trench, seepage from this source had to be taken care of. Until the trench attained depth, this flowed under the sheet piling to the pumps. Later a drift was cut from the upstream side of the trench to connect with the drift leading to the pumps. Before concrete was placed, this water was trapped and carried through the trench in an 8-inch pipe, which was subsequently closed by a valve at each end and filled with grout. Although it had to travel three times as far and had 20 feet less head to force it through the fill, the flow of water from downstream equalled or exceeded that from upstream, showing that the measures taken to curtail seepage from above were effective.

The upper part of the trench was excavated by a steam shovel. With the water drained out of it, the material would stand at a slope of 50 to 60° from the horizontal for a height of 60 to 80 feet. After sheeting was introduced, the usual practice was to drive the piling a foot and then to excavate to or close to its bottom level. Thus, if a bowlder was encountered, it could be removed to facilitate driving. Structural steel wales and bracing, with welded joints, held apart the two rows of sheeting, which were later embedded in the concrete. The 6,000 cubic yards of concrete required to fill the trench was placed in a continuous pour. The cut-off wall was completed 170 days after the river had been diverted.

The upper 24 feet of the cut-off wall is a horizontal true arch, 32 feet thick, with an upstream-face radius of 200 feet: the lower section is in the form of a wide-angle *V*, pointed upstream. It is 26 feet thick at the top and decreases with depth to a thickness of 21 feet at the bottom because of the tendency of the piling to bend inward at the bottom when driven. In the top of this wall there is a groove 3½ feet deep and varying in width from 7 feet at the axis of the dam to 6 feet 4 inches at the edges of the canyon walls. In this slot is set the base of the concrete apron on the upstream face. The apron is 5 feet thick where it notches into the cut-off wall, narrows to 36 inches 18 feet above its base, and then tapers to 23 inches at El. 12,640 and to 10 inches at the top.

In the lower 170 feet of the apron are three vertical contraction joints. One is on the axis of the dam and extends from the top of the cut-off wall at El. 12,470 to El. 12,640. The two others are 80 feet from the respective sides of the center line and extend from El. 12,530 to El. 12,640. These joints were made by leaving a 1-inch space and filling it with soft wood which would undergo crushing when the gaps closed. Each joint is sealed with a soft copper plate the edges of which are embedded in the concrete on both sides of the joint and assume the form of a 3-inch-deep *U* in the joint. Back of the plate is a pocket filled with coal-tar pitch, while the space in front of the plate is calked with oakum soaked

EXCAVATING TRENCH FOR CUT-OFF WALL

So that the concrete cut-off wall on which the heel of the dam rises would rest on rock, it was necessary to sink a trench through the 140 feet of glacial drift that filled the narrow gorge at the dam site. The first 70 feet was removed in open cut, after which two rows of steel sheet piling were driven. Upon reaching rock, a notch or keyway was drilled and blasted. This notch was also carried up the canyon walls. Drilling was done with Ingersoll-Rand S-49 Jackhamers. The bottom of the trench is shown at the right. The lower ends of some of the interlocking steel piles are visible at the upper right, and at the upper left are seen some of the cross members used for bracing. These were later embedded in the concrete.

in pitch and held by a metal plate bolted to the face of the apron.

From El. 12,640 to the top of the dam the apron has vertical contraction joints at intervals of 40 feet. That portion of the face will be exposed for weeks at a time, during periods when the water is drawn down, to daily variations in temperature, which are considerable at this latitude and altitude. The part of the apron below El. 12,640 will be continuously submerged, and the temperature variation will not exceed 10° to 15°F. In addition to taking care of contraction and expansion attributable to temperature changes, both sets of joints will serve another important purpose—that of allowing the apron to adjust itself to any horizontal movement of the dam.

Another feature of the design that is intended to permit the apron to adjust itself to any horizontal movement of the dam with a minimum of damage is the horizontal curvature given to the upstream face. The rubble masonry of the upstream face of the derrick-laid wall and, consequently, the concrete apron which it supports, conform to the outer contour of a cylinder with a 3,000-foot radius the axis of which is in the same vertical plane as the axis of the dam. Measured by the rise at the axis of the dam, the convexity amounts to 0.91 foot at the bottom of the apron where the distance between opposite canyon walls is 140 feet, and to 11.67 feet at the top of the apron where the canyon walls are 500 feet apart.

From the top of the cut-off wall at El. 12,470 to El. 12,660, the apron is reinforced with a double layer of steel bars, each layer containing both horizontal and vertical members. The vertical bars of one layer are 4 inches from the front face at the bottom, the distance decreasing at El. 12,510 and 12,550 to 3½ inches and 3 inches, respectively. In the back layer, the vertical rods are a like distance from the rear face of the apron. Above El. 12,660 there is but one layer running in both directions and placed on the center line of the apron. The accompanying table shows the sizes of the rods and details of their spacing.

The apron is notched into sound rock in the side walls of the gorge to an average distance of 5 feet, the penetration being greatest at the bottom and decreasing gradually towards the top. One-inch square bars, anchored from 3 to 5 feet in the side-wall trenches, project alternately 7½ and 15 feet into the apron just back of the front layer of reinforcing, as given in the table. This special reinforcing is designed to prevent cracking of the apron along and near the side walls where it is held firmly and cannot follow any downstream movement of the body of the dam.

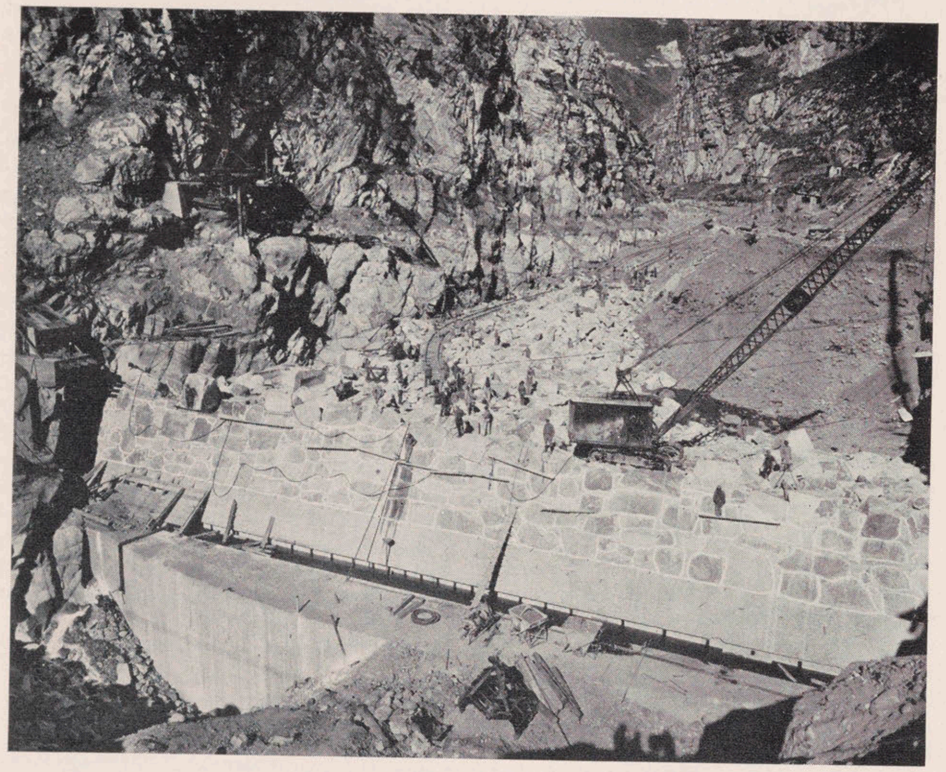
Another construction measure was adopted to help prevent serious cracking of the apron at the sides. Downstream of the side-wall trenches the rock sides of the canyon converge, and into these projecting flanks there was cut a series of shoulders or steps leading toward the axis of the dam. The derrick-laid rock wall rests against these rigid shoulders, and as its thickness increases gradually for a short distance out from the side walls, the amount of its yielding or compression at those points under loading was assumed to be approximately proportionate to the thickness of the wall from apron to shoulder. Thus provision has been made for a gradual increase in the movement of the apron as the distance increases from the side-wall trenches, where there can be no movement. It was believed that this would permit the apron to adjust

Between Elevations	Horizontal Reinforcement Front	Horizontal Reinforcement Back	Vertical Reinforcement Front	Vertical Reinforcement Back
12,470 & 12,510	1″ rd 9.0″ ctrs	1″ rd 18″ ctrs	1″ sq 20″ ctrs	1″ sq 40″ ctrs
12,510 & 12,550	1″ “ 10.5″ “	1″ “ 21″ “	1″ “ 24″ “	1″ “ 48″ “
12,550 & 12,595	⅞″ “ 10.5″ “	⅞″ “ 21″ “	1″ “ 28″ “	1″ “ 56″ “
12,595 & 12,660	⅞″ “ 12.0″ “	⅞″ “ 24″ “	1″ “ 32″ “	1″ “ 64″ “
	On Center		On Center	
12,660 & 12,680	1″ rd 10″ ctrs		1″ sq 20″ ctrs	
12,680 & 12,700	1″ “ 12″ “		1″ “ 24″ “	
12,700 & 12,725	1″ “ 14″ “		1″ “ 28″ “	

itself, without serious cracking, to the downstream movement of the dam resulting from settlement and compacting under the water load.

The foot of the apron was sealed into the groove in the top of the cut-off wall in a manner that would allow it to move a short distance downstream with the dam. The top of the cut-off wall was expected to remain rigid or to move only slightly, so provision had to be made for the independent movement of the base of the apron. This was done by giving it a thickness less than the width of the groove. At the axis of the dam there is 24 inches of surplus space, of which 18 inches is on the downstream side of the apron and 6 inches on the upstream side. The groove gradually narrows towards the ends of the dam, and at the side walls the surplus space totals 10 inches, of which 4 inches is on the downstream side of the apron and 6 inches on the upstream side. The uniform space of 6 inches on the upstream side was filled with coal-tar pitch immediately after the apron was poured. The downstream space, varying from 4 to 18 inches in width, was filled with pitch for three-quarters of its height before the foot of the apron was poured. Pockets were left in the concrete cut-off wall downstream of the groove into which the pitch would be forced under the application of sufficient pressure. In addition, ducts of 6-inch diameter leading from each pitch pocket to the downstream face of the cut-off wall were placed in the concrete so that, in case of a relatively large downstream movement of the apron, the pitch would be extruded. A copper plate was sealed into the concrete at the bottom of the groove and into the upstream face of the apron about 9 inches above its base. The plate passes over a 2-inch wood roller that was originally about 6 inches above the line where the plate enters the concrete of the apron.

Provisions were made to measure the movement of the heel of the dam at three points in the bottom of the apron just above the cut-off wall. Point No. 1 is 3 feet to the right of the axis, Point No. 2 is 42 feet farther to the right, and Point No. 3 is 37 feet to the left of the axis. Between October 3, 1936, when pouring of the apron was completed, and January 29, 1937, when the reservoir was full to the free spillway crest for the first time, the downstream movement at Point No. 1 was 6 inches; 7⅛ inches at Point No. 2; and 7¼ inches at Point No. 3. These measurements may be inaccurate by as much as ½ inch because of changes, attributable to temperature variations, in the length of the cable by which they were transmitted from the foot of the apron to an observation station above the water line of the full reservoir. Up to the autumn of 1938, the total observed movement at the three points was: 7 inches at No. 1; 9⅜ inches at No. 2; 10¼ inches at No. 3.

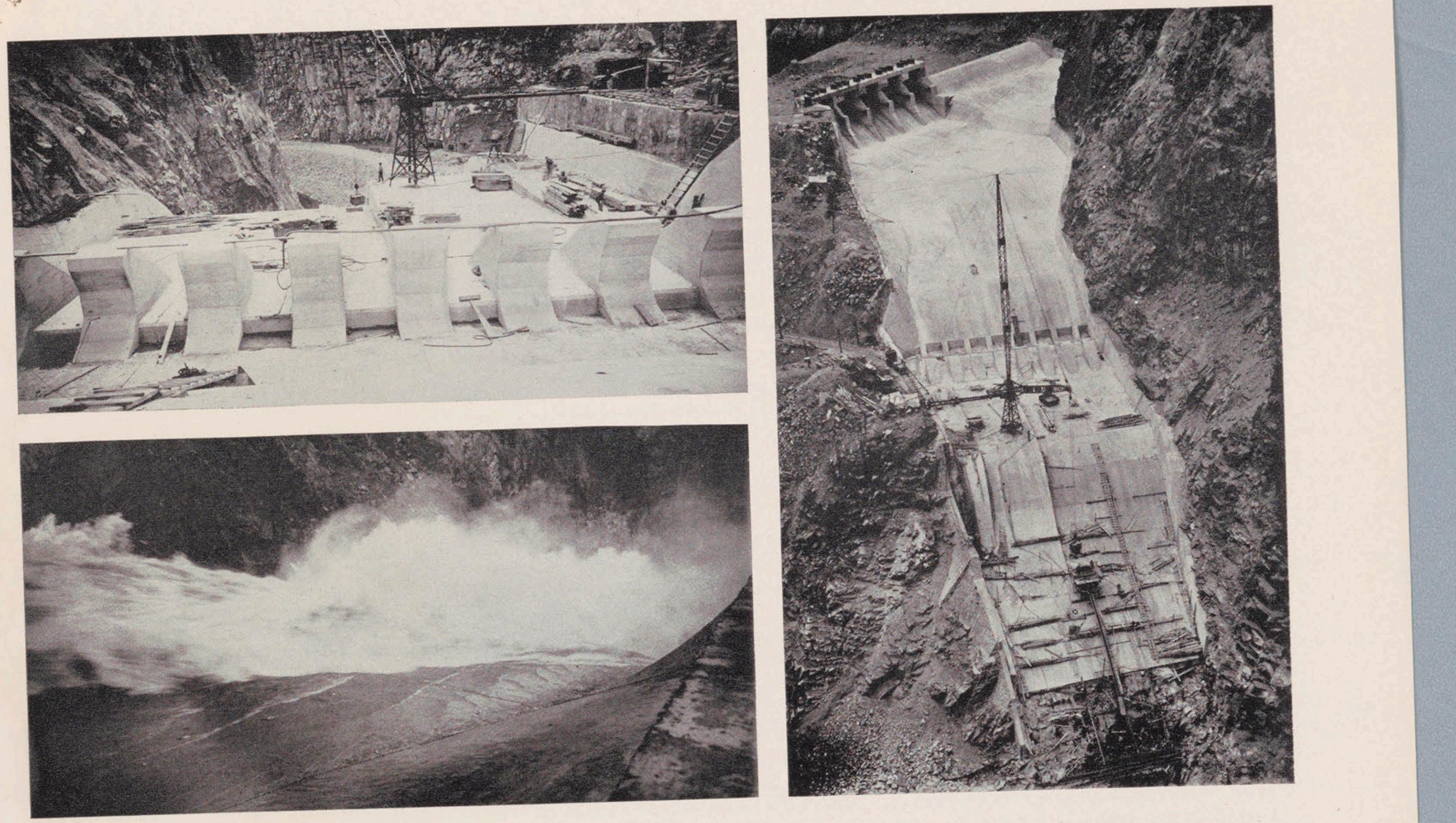


BASE OF RUBBLE WALL

This wall was laid in portland-cement mortar and backs up the derrick-laid dry wall that forms the nucleus of the upstream section of the dam. The rubble wall shown here was faced with a concrete apron which extends down into the groove visible in the top of the cut-off wall. By comparing the height of individual pieces of rock in the wall with that of the human figures, it will be observed that some very large stones were placed in the structure.

The continued tightness of such a dam depends largely upon the amount of its settlement and upon the extent to which the concrete apron can adjust itself to the movement without opening up leakage cracks. It was therefore important that means be provided for measuring the settlement. The internal settlement and compacting of the material on which the dam rests are combined in the total settlement. Both were measured at intervals after placing of the rock began. In order to measure the compacting of the foundation material, a 2-inch pipe was cemented into a large rock in the bottom course of the derrick-laid wall. As the wall rose in height, the pipe was extended to the top of the dam. By taking the elevation of the top of this pipe at regular intervals it was possible to determine how much the foundation was being compacted. The data thus obtained are plotted in an accompanying illustration. The rock in which the pipe is cemented is about on the axis of the dam, 114 feet from the heel. Directly above it, the wall rises to its greatest height, so that the rock load on the base can be assumed to be the maximum. During the construction of the derrick-laid wall, observations were made to determine the combined foundation compacting and the internal settlement of the wall. The results were not satisfactory nor conclusive; but the readings indicated that the internal settlement was small.

Observations were also made during the course of construction of points on the face of the rubble-masonry wall to determine the horizontal movement of the derrick-laid portion of the dam. These points were on the axis of the dam at El. 12,532.5, 12,571, 12,614, 12,655, 12,684, and 12,725—the top—and were designated as points *A*, *B*, *C*, *D*, *E*, and *F*, respectively. During the ten months starting with May, 1935, Point *A* moved downstream 0.12 foot. By October 1, 1936, when it was submerged, it had returned upstream 0.09 foot, thus leaving it 0.03 foot downstream from its original position. Between October 14, 1935, and February 6, 1936, Point *B* moved downstream 0.32 foot and then returned 0.17 foot by October 1, 1936, when it was submerged permanently. Between February 6, 1936, and June 8, 1936, Point *C* moved downstream 0.3 foot, returned 0.1 foot in the next 32 days and again moved slowly downstream, its net movement to October 6, 1936, being 0.3 foot downstream. Point *D* moved steadily downstream a total distance of 1.2 feet between April 15, 1936, and November 30, 1936. Point *E* likewise had no backward movement and traveled 1.62 feet downstream between May, 1936, and November 30, 1936. Point *F* had a similar unbroken movement of 1.61 feet downstream between July 6, 1936, and November 30, 1936. During construction, the rubble-masonry face of the derrick-laid wall was always brought out to the line it would have followed had there been no horizontal movement between successive lifts. As a consequence, the upstream face



SPILLWAY

The spillway drops 200 feet in a distance of 800 feet; and because of the erosive action of the water, it was necessary to pave the rock face of the canyon wall. At the right is a general view made during the construction period. To arrest the speed of the water, an "energy killer" was placed at about the half-way point. This is shown in detail at the upper left. Each concrete pier is 6 feet wide and 9 feet high, and its upstream face is designed to reverse the direction of the water striking it. A view from overhead (lower left), showing the effect of 14,000 second-feet of water entering the basin. Near the bottom of the spillway is a second energy destroyer, based on the principle of the hydraulic jump.

of the rubble masonry and also of the concrete apron was slightly dished, its profile in a vertical plane parallel to the axis of the dam being slightly concave upstream.

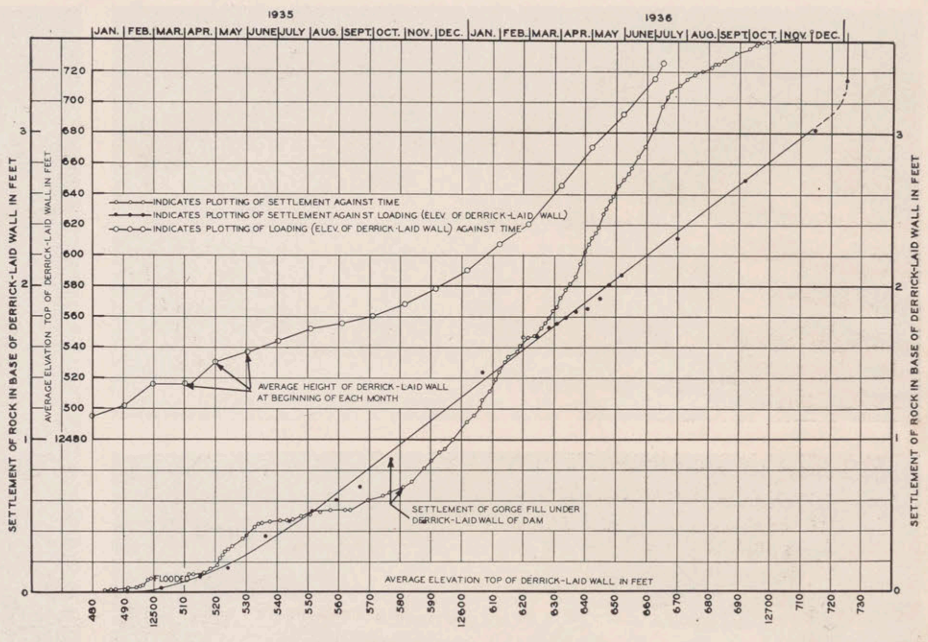
Upon completion of the concrete apron to the top of the derrick-laid wall, at El. 12,725, brass bolts were set in its top and spaced 9 inches on each side of the contraction joints, which are 40 feet apart. Their elevations and the distance of each one from a reference line normal to the axis of the dam were determined and recorded. At frequent intervals since then, observations have been made to ascertain both the horizontal and vertical movements of these markers, and they will be continued until the movement of the dam has ceased. Between October 3, 1936, and February 26, 1939, the horizontal movement of the bolt on the axis was 1.82 feet and its vertical movement was 0.89 foot. About half of this movement took place during the four months from October, 1936, to January, 1937, inclusive, during which the pond was filled for the first time. The movement has been proportionately less towards the side walls. The vertical movement has been about half the horizontal movement, as it should be, so long as the integrity of the apron and the upstream slope of the dam, 2 vertical to 1 horizontal, is preserved.

The steps that were taken to make the dam reasonably watertight have proved to be quite effective. It is believed that not more than 3½ second-feet of water is now passing the dam site and that half of this, or perhaps even more, is passing through the canyon side walls beyond the zone reached by grouting. The figure of 3½ second-feet is arrived at by adding to the surface or visible flow, measured by a weir in the river channel 1,000 feet below the dam, an estimate of the subsurface flow. Three pipes, approximately in an upstream and downstream line, were driven into the old bed of the river below the dam to make it possible to obtain readings of ground-water elevations at regular intervals. The first and third pipes are 210 feet apart, and the second is 19.5 feet from the first one.

In any period in which there has been no recent rain or no passage of water over the spillway, a rise of the water table accompanied by an increase in its slope would indicate that the volume of leakage through the dam has increased. Conversely, a lowering of the water table and decrease in its slope would indicate a diminution in leakage. From October, 1936, to October, 1938, the normal difference in the elevation of the water in Pipes Nos. 1 and 3 with full reservoir was 1 foot, thus indicating a slope of the water table of 1 in 210 feet, or 0.00476. Water in Pipe No. 2 stood uniformly about 0.1 foot below that in Pipe No. 1. These observations furnish ground for the inference that there has been a fixed amount of dam leakage with a full pond. Since last October there has been a reduction in the slope of the water table, which would seem to indicate that the leakage has decreased since that time.

The spillway for the dam was formed by cutting a channel into the rock of the canyon wall at the end of the dam on the left bank. The spillway weir is in two sections. Adjacent to the dam, with their crests at El. 12,705, are five Taintor gates, each 20 feet wide. In line with these, and extending toward the canyon wall, is a free spillway 134 feet long, with its weir crest at El. 12,715. With the reservoir surface at El. 12,723.33, the discharge capacity of the spillway weir is more than 36,000 second-feet, but it is expected that not more than one-third of this volume of water will have to be passed over the dam, save at infrequent intervals.

The period of greatest run-off of the Mantaro River watershed is from January to March, which is the time of greatest rainfall and also the summer season when snow melts in the higher reaches of the Andes. Severe rains may also fall in November and December, and in some years they continue into April and May. During the months of greatest river flow, the gates of Upamayo Dam will be closed to divert water into Lake Junin for storage, and this diversion will, it is estimated, reduce the volume of flow at Malpaso Dam by 40 per cent. By drawing down the water behind Malpaso Dam 15 to 20 feet prior to the rainy season, additional storage capacity will be provided there. These measures, together with the discharge of water for power generation, are calculated to reduce the spillway flood discharge to about one-half the uncontrolled flood flow of the river at Malpaso Canyon. By the exercise of vigilance, and by the use of good judgment in controlling the reservoir level by spillway gates and power-station operation, it is believed that the spillway discharge can be kept down to between 6,000 and 10,000 second-feet in most years and that a discharge of 12,000 second-feet will be rare.



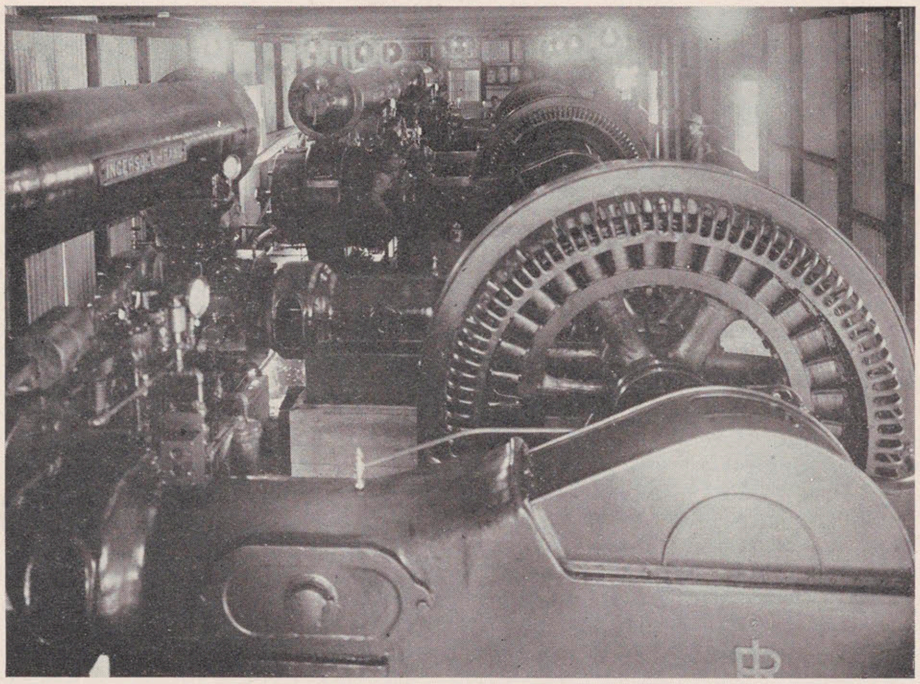
EXTENT OF FOUNDATION SETTLEMENT

Graph of data obtained by taking, at regular intervals during construction, the elevation of the top of a pipe cemented into a large rock in the bottom course of the derrick-laid wall and carried upward as the wall rose in height.

Water flowing over the spillway drops nearly 200 feet in 800 feet. The rock of the mountainside over which it descends was so badly cracked and broken that it was evident that it would be rapidly eroded by the water. Accordingly, it was necessary to pave it with concrete. The floor pavement of this channel has an average thickness of 24 to 30 inches. It is reinforced in both directions and securely anchored to the rock by 1⅛-inch square bolts, one to 80 square feet of concrete. Vent holes prevent uplifting of the pavement by water passing underneath it. The sides of the channel are also faced with reinforced concrete to a height of 10 or 12 feet, and on the mountainsides these walls are doweled to the rock and amply vented.

To reduce the high velocity the water would attain at the lower end of the channel by reason of the steepness of the slope, an "energy killer" was placed in the channel about half way down. This takes the form of a shallow basin about 30 feet long and 100 feet wide. At its downstream edge is a concrete shoulder 30 inches high, and rising from this are eight concrete piers each 6 feet wide and 9 feet high. These are spaced 12 feet apart, center to center, leaving 6-foot openings between adjacent ones. The upstream faces of the piers are shaped so that the water striking them returns upstream. Water enters this basin in an unbroken stream with a velocity of 50 to 60 feet a second, and leaves it very much broken up and frothy with a velocity of 20 to 30 feet a second. A short distance from the final drop, about 200 feet from where the spillway joins the old channel of the river, there is a second energy destroyer. Its design is based on the principle of the hydraulic jump.

The Malpaso Canyon Dam and appurtenant works were constructed by the Cerro de Pasco Copper Corporation under the direction of Harold Kingsmill, general manager of its operations in Peru. J. F. Foran was superintendent of construction. The engineering was done by Sanderson & Porter of New York, N. Y., and H. H. Haggard of that firm was on the job throughout the construction period.



AIR COMPRESSORS

Compressed air was supplied by these three Ingersoll-Rand Class PRE-2 machines, each of which delivered 1,738 cfm. They were driven by direct-connected synchronous motors. Most of the air was used to operate rock drills in driving the power and diversion tunnels, in excavating at the dam site, and in quarrying the rock incorporated in the dam. The tunnels were driven by the heading-and-bench method and with Ingersoll-Rand drifter drills. In the quarry, large quantities of rock were brought down with each blast by the "coyote" method—by drilling tunnels and crosscuts into the rock face and placing large charges of explosives in them. This drilling, as well as that in the canyon bottom and side walls, was done with S-49 Jackhamers.