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GEOLOGICAL SURVEY CIRCULAR 483

SUMMARY OF DEVELOPED AND POTENTIAL WATERPOWER OF THE UNITED STATES AND OTHER COUNTRIES OF THE WORLD, 1955–62

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SUMMARY OF DEVELOPED AND POTENTIAL WATERPOWER OF THE UNITED STATES AND OTHER COUNTRIES OF THE WORLD, 1955-62

By LOYD L. YOUNG

ABSTRACT

Estimates of potential waterpower and historical data on waterpower developments in various parts of the world are assembled in this report. Salient characteristics of the period studied, 1955-62, include increased use of the underground powerhouse, multiple-purpose developments, and use of storage (including pumped storage) to increase the value of waterpower for peaking purposes. High-voltage long-distance transmission has been improved, especially in the United States, Sweden, and the U.S.S.R., and generating facilities tend to be larger than ever before. Asia leads the continents in total potential waterpower; Europe is first in use of waterpower. In rate of increase of waterpower installations and in percent of hydroelectric to total installations Africa is first among the continents. The 1955-62 period saw a great increase in per capita consumption of electric energy. Norway leads all countries with annual consumption of about 9,000 kwhr per capita. Waterpower development was carried on in a majority of the countries of the world and in most of them at an accelerated rate.

INTRODUCTION

The Geological Survey first made an estimate of the potential waterpower of the United States in 1908 and of the world in 1918. The latter estimate (U. S. Geological Survey, 1921) was prepared for the Versailles Peace Conference. Jones and Young (1954) presented revised estimates as of December 1952, and Young's report (1955) brought them up to December 1954. The present paper reviews developmental progress between January 1, 1955, and December 31, 1962, and contains estimates as of December 31, 1962.

The literature reviewed is mostly from the free world but is restricted to it only because published material about current happenings elsewhere is limited. Statistical information on developed waterpower is included for all countries where such information has been found, and estimates of potential power at discharge available 95 percent or more of the time and for arithmetical average discharge are also included for most countries.

SUMMARY OF DEVELOPMENT, JANUARY 1, 1955-DECEMBER 31, 1962

With the development of atomic energy for peaceful use, many expected that water as a source for electrical energy had almost fulfilled its usefulness. Insofar as hydroelectricity is affected, the opposite has taken place, however, and present investigations of some fabulous waterpower sites in remote areas of the world indicate that the future contribution of hydroelectric power to world progress may exceed that made by it in the past. When nuclear power becomes a material factor in the overall power picture, it is expected that waterpower, especially at reservoirs and from pumped storage, will gain importance as a peaking source. Once a large atomic plant is operating, it can continue to run in the offpeak hours pumping water to high-level reservoirs for release during peaking hours. Also, reservoirs with capacity to regulate can hold the natural flow of a stream for peaking-hour use.

Use of underground powerhouses is increasing. Such plants have been constructed in at least 29 countries (Lawton, 1959). Italy and Sweden lead in underground plant construction and usually choose the underground site for economy. An underground plant may be placed almost directly under the stored water and eliminate the necessity for a surge tank. Penstock length is often reduced and the tunnel required to carry the water from the tailrace may be relatively inexpensive. Other benefits are: greater heads, larger plants, use of blasted rock in dam construction, highly developed blasting techniques, and reduced maintenance and depreciation costs (Nilsson, 1960).

Another significant recent trend is the addition of power facilities at dams already in service for flood control, irrigation, or municipal supply. The 60-MW (megawatt) plant planned for the existing Lucky Peak flood-control reservoir on Boise River, Idaho, is an example of this.

The South Carolina Electric and Gas Co. will have atomic, hydroelectric, and coal-fired plants at one location near Parr, S. C., when a 17-MW nuclear plant now under construction is completed.

High-voltage long-distance transmission has increased, especially in the United States, Sweden, and the U.S.S.R. The U.S.S.R. transmits the highest voltage (525 kilovolt) and is planning an 800-kv line for the Urals. Direct-current transmission is being seriously studied in many countries and some important lines are now in operation. Leaders in this field are England and France (cross channel), New Zealand, Sweden, and the U.S.S.R. An experiment in direct-current transmission is now being conducted by the Bonneville Power Administration, Dept. of the Interior. A 5-mile 1.1-million volt d.c. line at The Dalles Dam on the Columbia River, Oregon and Washington, is the experimental line.

Several estimates of potential power have been made since 1955. The United Nations Economic Commission for Europe has made official or preliminary estimates for most of the European countries. In 1962 the Geological Survey's Branch of Waterpower Classification completed a revised estimate of potential power at all sites judged technically feasible of exploitation in the public-land States. Table 10 in the "United States" section of this report presents the new estimate by States for the various sections of the country.

The installed capacity of waterpower plants on December 31, 1962 was 38,600 MW (1,000 kilowatts) for the United States and 180,938 MW for the world. Potential waterpower for average discharge of streams and gross head sites is estimated to be 121,346 MW for the United States and 2,724,044 MW for the world.

The principal hydroelectric developments in North and Central America and in the West Indies were in the United States, Canada, and Mexico. In South America, Brazil effected the most installations; but growth rates were greatest in Venezuela, Argentina, and Ecuador. Notable developments in Africa included Kariba Gorge dam, reservoir, and powerplant on the Zambezi River, the installation of generating facilities at the existing Aswan dam, and the beginning of work on the High Aswan dam on the Nile. Japan continued to lead Asian countries in waterpower installations, but many significant developments were achieved elsewhere on the continent. The Snowy Mountain project in Australia was outstanding among world engineering achievements. Leading waterpower developers in western Europe were Switzerland, Sweden, Italy, France, Austria, Norway, Portugal, and Spain. In eastern Europe and in Asia, the U.S.S.R. accelerated the rate of waterpower development concentrating on largeness in all aspects of dams, reservoirs, generating plants, and transmission lines.

In 1954 Hoover Dam on the Colorado was the world's highest—726 feet. Including dams under construction, Hoover is now ninth in height, as indicated by table 1. Not shown in table 1 are 3 dams approved for construction in the U.S.S.R. (Chirkeyskaya 755-foot concrete, Sayanskaya 738-foot rockfille, Charvakskaya 505-foot rockfill) and 13 dams built in the United States before 1955 (Hoover on Colorado River, Nev.-Ariz. 726-foot arch; Shasta on Sacramento River, Calif., 602-foot gravity; Hungry Horse on South Fork Flathead River, Mont., 564-foot arch; Grand Coulee on Columbia River, Wash., 550-foot gravity; Ross on Skagit River, Wash., 540-foot gravity; Fontana on Little Tennessee River, N. C., 480-foot gravity; Lower Baker on Baker River, Wash., 465-foot gravity; Anderson Ranch on South Fork Boise River, Idaho, 456-foot earth; Detroit on North Santiam River, Oreg., 454-foot gravity; Pine Flat on Kings River, Calif., 440-foot gravity; O'Shaughnessy on Tuolumne River, Calif., 430-foot gravity; Mud Mountain on White River, Wash., 425-foot rockfill; and Owyhee on Owyhee River, Oreg., 417-foot gravity arch).

Table 1.—High dams completed or under construction between 1955 and 1962

Dam	Country	River	Height (ft)	Type
Ingurskaya[1]	U. S. S. R.	Ingura	988	Arch.
Nurek[1]	do	Vakhsh	984	Rockfill.
Grande Dixence	Switzerland	Dixence	932	Gravity arch.
Vaiont	Italy	Vaiont	873	Arch.
Mauvoisin	Switzerland	Dranse de Bagnes	777	Do.
Tachia[1]	Formosa	Tachia	780	Cupola arch.
Bhakra	India	Sutlej	740	Gravity.
Oroville[1]	U.S.A., Calif	Feather	735	Earth gravel.
Glen Canyon[1]	U.S.A., Ariz	Colorado	710	Gravity arch.
Manicouagan[1]	Canada	Manicouagan	650	Multiple arch.
Kurobe	Japan	Kurobe	636	Arch.
Dez	Iran	Dez	630	Do.
Kurobegawa	Japan	Kurobe	617	Cupola arch.
Portage Mountain[1]	Canada	Peace	600	Earth rock.
Tignes	France	Isere	593	Arch.
Karadj	Iran	Karadj	590	Do.
Trinity	U.S.A., Calif	Trinity	537	Earth rock.
Yellowtail[1]	U.S.A., Mont	Big Horn	520	Arch.

Table 1.—High dams completed or under construction between 1955 and 1962--continued

Dam	Country	River	Height (ft)	Type
Cougar[1]	U.S.A., Oreg	S. F. McKenzie	515	Gravity.
Okatadami	Japan	Tadami	515	Do.
Swift	U.S.A., Wash	Lewis	512	Earth.
Bhumiphol[1]	Thailand	Ping	508	Gravity arch.
Flaming Gorge[1]	U.S.A., Utah	Green	502	Arch.
Roseland	France	Roseland	490	Do.
Donnells	U.S.A., Calif	M. F. Stanislaus	484	Do.
Carters[1]	U.S.A., Ga	Coosawattee	464	Earth rock.
Warragamba	Australia	Warragamba	450	Gravity.
Round Butte[1]	U.S.A., Oreg	Deschutes	440	Rockfill.
Miboro	Japan	Sho	430	Do.
Kariba	Rhodesia	Zambezi	420	Arch.
Bratsk	U. S. S. R	Angara	410	Earth.

[1]Under construction.

In 1954 Lake Mead's 30 million acre-feet behind Hoover Dam was surpassed in capacity by only one manmade reservoir—Owens Falls on the Nile in Uganda, which added 169,500,000 acre-feet of storage capacity to Lake Victoria. Thirteen reservoirs capable of storing more than 30 million acre-feet of water were completed or under construction between 1955 and 1962. Some of the larger reservoirs of the period are shown in table 2.

Table 2.—Large reservoirs completed or under construction between 1955 and 1962

Reservoir	Country	River	Storage (millions of acre-feet)
Kariba	Rhodesia	Zambezi	149
Bratsk	U. S. S. R	Angara	145
Akosombo[1]	Ghana	Volta	120
Manicouagan[1]	Canada	Manicouagan	115
High Aswan[1]	Egypt	Nile	104
Portage Mtn[1]	Canada	Peace	62
Krasnoyarsk[1]	U. S. S. R	Yenisei	59
Sanmen Gorge	China	Yangtze	53
Kuybyshev	U. S. S. R	Volga	47
Mangla	Pakistan	Jhelum	45
Bukhtarminsk	U. S. S. R	-------	43
Irkutsk	do	Angara	37
Wainganga[1]	India	-------	33
Glen Canyon (Lake Powell)	U.S.A., Ariz.-Utah	Colorado	28
El Fuerte	Mexico	-------	25
Garrison	U.S.A., N. Dak	Missouri	25
Oahe	U.S.A., S. Dak	do	24
Lake Ontario[2]	U.S.A., Canada	-------	24

[1]Under construction.
[2]Storage added.

The Grand Coulee powerplant, largest in 1954 with an installed capacity of 1,974,000 kw (kilowatts), is now in ninth place. The eight larger plants are shown in table 3.

Table 3.—Large powerplants completed or under construction between 1955 and 1962

Plant name	Country	River	Capacity (kw)
Krasnoyarsk[1]	U. S. S. R	Yenisei	6,000,000
Bratsk	do	Angara	4,500,000
John Day[1]	U.S.A., Oreg.-Wash	Columbia	3,105,000
Nurek[1]	U. S. S. R	Vakhsh	2,700,000
Volgograd	do	Volga	2,530,000
Portage Mtn	Canada	Peace	2,300,000
Kuybyshev	U. S. S. R	Volga	2,300,000
Robert Moses	U.S.A., N. Y	Niagara	2,190,000

[1]Under construction.

Now as in 1954, Fort Peck Dam (constructed in 1940) on the Missouri River in Montana holds first place for volume of dam at 125.6 million cubic yards, but 17 dams will have moved ahead of the 1954 second-place dam—32-million-cubic-yard Kingsley Dam (completed in 1942) on the North Platte River, Nebr.—when all dams under construction between 1955 and 1962 are completed. The dams in this group are shown in table 4.

Table 4.—Large dams completed or under construction between 1955 and 1962

Dam	Country	River	Volume of dam (millions of cubic yards)
Oahe[1]	U.S.A., S. Dak	Missouri	92
Oroville[1]	U.S.A., Calif	Feather	78
Mangla[1]	Pakistan	Jhelum	75
San Louis[1]	U.S.A., Calif	San Joaquin tributary	75
Garrison	U.S.A., N. Dak	Missouri	67
Portage Mtn[1]	Canada	Peace	60
Nurek[1]	U. S. S. R	Vakhsh	59
Kiev[1]	do	Dnieper	59
Aswan High Dam[1]	Egypt	Nile	53
Fort Randall	U.S.A., S. Dak	Missouri	50
Kakhouka	U. S. S. R		47
South Saskatchewan[1]	Canada	Saskatchewan	45
Tsimlyanskaja	U. S. S. R	Volga	44
Kuybyshev	do	do	44
Kremenchug	do	Dnieper	36
Dneprodzerzhinsk[1]	do	do	36
Volgograd	do	Volga	33

[1]Under construction.

Table 5—High-head waterpower projects completed or under construction between 1955 and 1962

Plant	Country	Head (ft)	Turbine
Kolbnitz[1]	Austria	5,810	Pelton.
Roseland	France	3,940	Do.
Valtellina	Italy	3,130	Do.
Lungchien	Formosa	2,930	Do.
Poatina	Tasmania	2,720	Do.
Aura	Norway	2,558	Francis.
Himsel	Norway	1,780	Pelton.
Guadeloupe	Colombia	1,762	Do.
McKay Creek	Australia	1,730	Do.
Murray No. 1	Australia	1,719	Francis.

[1]World's highest head.

LARGE RIVERS

In 1961 the U. S. Geological Survey's Water Resources Division prepared a worldwide list of rivers with an average discharge of 35,000 cfs (cubic feet per second) or greater from data collected as part of a study on worldwide runoff of dissolved solids. These rivers make an important contribution to waterpower production and potential and the list is presented in table 6. Attention is called especially to the column indicating rank of average discharge, which has been added for this report. South America's Amazon exceeds all rivers in average discharge; Africa's Congo is second, and Asia's Yangtze, third. Of the first 15 large rivers, 9 are in Asia. The Mississippi, our largest river, is seventh and the Columbia is nineteenth. Australia is the only continent without a river with average discharge great enough to be included in the tabulation.

Table 6.—Large rivers of the world

River	Country	Drainage area (thousands of sq mi)	Avg discharge at mouth (thousands of cfs)	Rank
	North America			
Mississippi[1]	U.S.A. and Canada	1,244	611	7
St. Lawrence	U.S.A. and Canada	498	500	11
Mackenzie	Canada	697	280	17
Columbia	U.S.A. and Canada	258	256	19
Yukon	Canada	360	180	24
Frazer	do	92	113	32
Nelson	do	414	80	37
Mobile	U.S.A.	42	58	43
Susquehanna	do	28	38	48
	South America			
Amazon	Brazil	2,231	[2]7,500	1
Orinoco	Venezuela	340	600	8
Parana	Argentina	890	526	10
Tocantins	Brazil	350	360	16
Magdalena	Colombia	93	265	18
Uruguay	(3)	90	136	26
Sao Francisco	Brazil	260	100	34
	Africa			
Congo	Congo	1,550	1,400	2
Zambezi	Mozambique	500	250	20
Niger	Nigeria	430	215	22
Nile	Egypt	1,150	100	33
	Asia			
Yangtze	China	750	770	3
Brahmaputra	E. Pakistan	361	700	4
Ganges	India	409	660	5
Yenisei	U.S.S.R	1,000	614	6
Lena	do	936	547	9
Irrawaddy	Burma	166	479	12
Ob	U.S.S.R	959	441	13
Mekong	Thailand	310	390	14
Amur	U.S.S.R.	712	388	15
Indus	W. Pakistan	358	196	23
Kolyma	U.S.S.R	249	134	27
Sankai (Si)	China	46	127	28
Godavari	India	115	127	29
Hwang Ho (Yellow)	China	260	116	31
Pyasina	U.S.S.R	74	90	36
Krishna	India	119	69	39
Indigirka	U.S.S.R	139	64	40
Salween	Burma	108	53	44
Shatt-al Arab[4]	Iraq	209	51	45
Yana	U.S.S.R	95	35	49
	Europe			
Danube	Romania	315	218	21
Pechora	U.S.S.R	126	144	25
Dvina (Northern)	do	139	124	30
Neva	do	109	92	35
Rhine	Netherlands and Germany	56	78	38

Table 6.—Large rivers of the world--continued

River	Country	Drainage area (thousands of sq mi)	Avg discharge at mouth (thousands of cfs)	Rank
		Europe--continued		
Dnepr	U.S.S.R	194	59	41
Rhone	France	37	59	42
Po	Italy	27	51	46
Vistula	Poland	76	38	47

[1]Includes Atchafalaya River.
[2]Department of Interior News Release 41939-64, Feb. 24, 1964
[3]Argentina and Uruguay.
[4]Tigris, Euphrates, and Karun.

UNMEASURED WATERPOWER SOURCES

Pumped storage, evaporation, and tidal power are three sources of waterpower frequently mentioned in the literature but not measured in this report although they seem of sufficient importance to be briefly discussed here.

The utility of pumped storage has now become widely recognized and its use is increasing rapidly. The largest pumped-storage plant in operation in 1950 was probably Witznaw in Germany (1943), which had a generating capacity of 212 MW in four 53 MW-units (Cooper 1956). Table 7, listing selected pumped-storage plants placed in operation after January 1, 1955, or under construction at the end of 1962, illustrates the present trend to larger pumps and generating units.

Table 7.—Selected pumped-storage plants placed in operation or under construction between 1955 and 1962

Plant	Country	Generating capacity(MW)	
		Unit size	Total
Limburg	Austria	60	120
Sir Adam Beck	Canada	30	180
Lunersee	Switzerland	----	225
American Niagara	U.S.A., N. Y	20	240
Ffestiniog	Scotland	75	300
Taum Sauk	U.S.A., Missouri	175	350
Crauchan	Scotland	100	400
Vianden	Luxembourg	100	900

Pump and generator sizes have grown in about the same proportion as size of total plant installations. Limburg is equipped with two 60-MW units, Taum Sauk will have two 175-MW units, and pumped-storage sets of 200 MW or larger are predicted. The investigations leading to decisions on Taum Sauk, located on the Ozark Plateau on the East Fork of the Black River in southeastern Missouri, eliminated an economic barrier to feasibility by increasing the head and thereby reducing the storage requirements. The smaller reservoir reduced the cost of land acquisition, as less land was required and its new location was on less valuable land (Water Power, Feb. 1961, p. 45). McCormack (1962) described Taum Sauk as one of the boldest hydroelectric undertakings of the 1960's.

Hassan, an Egyptian oceanographer, suggested (1961) that the Red Sea be dammed at both ends, allowing evaporation to lower it. He estimated that the evaporation in the area equals 12 feet per year and that eventually 1½ million cfs could be admitted to produce 50 million kw. Another scheme would admit water to the Qattara depression and would combine pumped storage with evaporation in a manner that would assure 100,000 kw and make as much as 340,000 kw available when the pumps are not running (Gohar, 1961).

The world's first major tidal-power project is now under construction on the Rance estuary near Saint Malo, France, where tides are among the strongest in the world. There are two high and two low tides in 24 hours and 50 minutes, and the difference in level between consecutive high and low tides may be as much as 44 feet. The project was started in 1960 and actual construction began in 1961. Completion is scheduled in 6 years. Installations will total 240 MW in 24 bulb sets, which can operate as pumps or turbines in either direction, and production will be equivalent to a plant factor of 26 percent for a conventional waterpower plant.

Many other parts of the world have sites favorable to the development of tidal power, including Passamaquoddy on the east coast of the United States, several locations along the west coast, and the Gulf of Alaska. Australia is actively investigating tidal powersites along the Kimberly coast.

DEVELOPED AND POTENTIAL WATERPOWER

WORLD

A summary of the developed and potential waterpower estimates for the world is shown by continents in table 8. The installed capacities are published figures or were estimated by adding to the latest published figures, capacities of installations believed to have been put on the line by December 31, 1962. The 10-year growth-rate column is based upon the assumption that it is normal to double power-generating facilities every 10 years. This general rule of thumb applies to all generating facilities and may not be applicable to waterpower facilities alone in a specific instance. Nevertheless, with the exception of North and Central America and West Indies, waterpower installations are currently being made in all parts of the world at a rate faster than would be necessary to maintain the normal growth rate for all installations. The column for percent of waterpower installations to total generating installations is included for the readers who wish to determine approximately a country's total electric-generating installations.

The potential power estimates in table 8 and those that follow represent, at 100-percent efficiency and gross head, that part of theoretical potential considered to be technically feasible of exploitation without regard to time (the total theoretical power of sites that may reasonably be assumed to be practicable). No estimate of economic potential or of time of development has been made although such estimates by others may be mentioned. For those who wish to make a deduction from 100 percent to an efficiency that might occur in practice, a multiplier of 0.75 to 0.80 is suggested (U. N. Econ. Comm. for Europe, 1961).

Table 8.—Installed capacity of hydroelectric plants, 10-year growth ratio, hydroelectric as percent of total generating installations, and estimated gross theoretical power of developed and potential sites of the world

Area	Installed capacity[1] (approx, in MW)	10-year growth ratio (normal = 2 Jan. 1, 1955 = 1)	Percent of total (approx)	Estimated gross theoretical potential (MW)	
				Q95	Arithmetic mean
America:					
North, Central, and West Indies	61,230	1.70	24	90,065	270,089
South	6,865	2.08	50	50,750	471,350
Africa	3,185	4.00	60	176,677	684,680
Asia	19,992	2.13	50	160,826	944,153
Australia and Oceania	3,860	2.60	40	18,600	143,750
Europe	[2]85,806	2.20	40	54,687	209,505
Total	180,938	----	--	551,605	2,724,044
Weighted avg	-------	2.04	33	-------	--------

[1]As of Dec. 31, 1962.
[2]Includes Asian U.S.S.R. Most of the U.S.S.R. developments are in Europe.

The columns in table 8 and those that follow are arranged so that the reader may judge a continent's or country's stage of development, progress, and possibilities, rather than compare one country with another. The tables may contain listings of countries that are not included in the discussions that follow. Only those countries are discussed for which either exceptional potential or recent significant activities can be reported.

NORTH AND CENTRAL AMERICA AND WEST INDIES

The principal hydroelectric development in North and Central America and West Indies between 1955 and 1962 was in the United States, Canada, and Mexico. (See table 9.) However, other countries in the area made progress. International development of the Niagara and St. Lawrence sites was achieved, and progress toward agreement in the Columbia River basin was made jointly by the United States and Canada. Mexico and the United States continued cooperative developments on the Rio Grande.

United States

A reappraisal of the gross theoretical potential waterpower of all sites, developed and undeveloped, was made during 1962 for 15 Western States, Alaska, and Arkansas. The objective of the study was to determine total "technically feasible" potential power at sites that may logically be considered for development. The estimators used the latest standards of the World Power Conference (1962) in order to obtain estimates comparable to those made in other parts of the world. The new estimates are consistently higher than the values reported by Young (1955) for these states. The increase can be credited to added information on streamflow and improved maps for locating and determining the capacity of powersites. The tendency of appraisers to make conservative estimates is lessened when the data available are sufficient and accurate. Table 10 presents the estimates by section of country and by State. The values in table 10 are from unpublished data by Mr. Arthur Johnson.

Table 9.—Installed capacity of hydroelectric plants, 10-year growth ratio, hydroelectric as percent of total generating installations, and estimated gross theoretical power of developed and potential sites of North and Central America and West Indies

	Installed capacity[1] (approx, in MW)	10-year growth ratio (normal =2 Jan. 1, 1955 = 1)	Percent of total (approx)	Estimated gross theoretical potential (MW)	
				Q95	Arithmetic mean
United States	38,600	1.66	17	34,000	121,346
British Honduras	U	U		75	375
Canada	20,315	1.80	83	43,240	71,250
Costa Rica	80	1.63	74	1,050	6,000
El Salvador	80	5.66	60	225	1,125
Greenland	[2]10	U	[2]61	750	11,250
Guatemala	30	1.20	51	1,575	9,000
Honduras	6	U	17	1,050	6,000
Mexico	1,900	2.47	44	6,375	33,750
Nicaragua	9	1.06	12	825	4,500
Panama and Canal Zone	65	1.32	47	525	3,000
West Indies	[3]135	1.95	24	375	3,000
Total	61,230	----	--	90,065	270,596
Weighted avg	------	1.70	24	------	-------

[1]As of Dec. 31, 1962.
[2]From United Nations (1961).
[3]Cuba 3 MW, Jamaica 13 MW, Martinique 9.6 MW, Puerto Rico 109.2 MW, St. Thomas 0.2 MW.

Table 10.—Gross theoretical waterpower in the United States at developed and undeveloped sites, and installed capacity of developed sites, December 31, 1962

	Gross theoretical power[1] (MW)			Installed capacity[2] (MW)
	Q95	Q50	Arithmetic mean	
New England	784.7	1,831.5	2,737.1	1,255.4
Maine	345.3	826.6	1,130.2	349.9
New Hampshire	220.1	411.8	684.1	397.2
Vermont	79.8	205.9	320.0	186.5
Massachusetts	100.0	240.2	374.5	185.9
Rhode Island	5.2	14.2	20.9	2.5
Connecticut	34.3	132.8	207.4	133.4
Middle Atlantic	3,330.9	5,866.6	7,357.1	4,407.4
New York	3,120.5	4,813.2	5,727.0	3,968.4
New Jersey	9.0	64.2	93.3	6.1
Pennsylvania	201.4	989.2	1,536.8	432.9

Table 10.—Gross theoretical waterpower in the United States at developed and undeveloped sites, and installed capacity of developed sites, December 31, 1962--continued

	Gross theoretical power[1] (MW)			Installed capacity[2] (MW)
	Q95	Q50	Arithmetic mean	
South Atlantic--------	1,542.0	3,866.6	5,716.6	3,844.3
Delaware--------	1.5	5.2	8.2	------
Maryland and the District of Columbia------	59.7	249.2	410.3	274.2
Virginia---------	188.7	568.5	909.4	395.9
West Virginia----	182.8	786.3	1,194.3	100.9
North Carolina---	343.9	845.2	1,085.4	1,266.0
South Carolina ---	431.9	766.1	914.6	932.1
Georgia ---------	327.5	614.0	1,133.2	833.0
Florida ---------	6.0	32.1	61.2	42.2
East South Central ---	1,984.3	3,756.2	5,574.9	4,193.0
Kentucky --------	235.7	460.3	871.3	540.9
Tennessee-------	990.7	1,775.5	2,419.3	1,921.2
Alabama --------	720.6	1,420.4	2,004.5	1,730.9
Mississippi------	37.3	100.0	279.8	------
East North Central ---	755.9	1,712.9	2,596.1	820.3
Ohio ------------	18.7	81.3	156.0	5.0
Indiana----------	40.3	138.8	243.9	29.7
Illinois----------	211.9	530.4	847.5	38.7
Michigan --------	238.0	426.0	628.1	370.9
Wisconsin -------	247.0	536.4	720.6	376.0
West North Central---	1,213.1	3,157.0	4,285.1	1,760.3
Minnesota -------	160.4	393.9	639.3	152.5
Iowa ------------	81.3	246.9	407.3	138.0
Missouri --------	311.8	700.5	1,050.4	392.6
North Dakota ----	150.0	293.9	347.5	400.0
South Dakota-----	229.4	849.2	961.3	433.0
Nebraska--------	229.0	492.6	620.6	238.3
Kansas----------	51.2	180.0	258.7	5.9
West South Central ---	499.2	1,251.1	2,573.3	1,033.6
Arkansas--------	102.4	562.5	1,170.0	478.3
Louisiana -------	38.0	72.4	246.2	-------
Oklahoma -------	135.0	310.3	590.1	165.4
Texas-----------	223.8	305.9	567.0	389.9
Mountain ------------	7,147.7	14,626.7	26,939.7	4,610.0
Montana---------	1,767.9	3,231.2	4,899.6	1,318.9
Idaho------------	3,058.0	5,928.6	11,374.1	1,031.5
Wyoming --------	282.8	578.4	1,410.2	291.4
Colorado --------	418.9	978.3	2,439.8	265.5
New Mexico -----	67.5	201.3	433.0	24.3
Arizona ---------	1,109.8	2,612.7	4,361.4	892.7
Utah ------------	306.0	754.2	1,604.7	102.9
Nevada----------	136.8	342.0	416.9	682.8
Pacific--------------	16,512.6	35,981.6	63,566.2	16,675.4
Washington ------	7,872.9	14,107.1	20,659.9	9,245.7
Oregon----------	4,067.8	7,819.1	12,389.2	2,695.4
California -------	2,119.9	6,563.6	13,073.1	4,624.4
Alaska ----------	2,385.0	7,305.8	17,164.0	76.0
Hawaii ----------	67.0	186.0	280.0	33.9
Total, all states	33,770.5	72,050.2	121,346.1	38,599.6

[1]Values for—Mountain and Pacific Divs. (except Hawaii); Dakotas, Kansas, and Nebraska in West North Central Div.; and Arkansas in West South Central Division—from studies made during 1962. All other values from Young (1955, table 3).

[2]Values for—Mountain and Pacific Divs. (except Hawaii); Dakotas, Kansas, and Nebraska in West North Central Div.—from studies made in 1962. All other values from Electrical World (1963).

New interest is being shown in waterpower resources in all parts of the United States, and the need for more reliable information is being realized by officials and the public alike. In 1960 a U. S. Senate Select Committee conducted an investigation of water resources activities and made a report. The status of our knowledge of the amount of waterpower technically or theoretically capable of development in this country and the proportion of it that we expect to develop was examined critically by Netschert (1960), who pointed out the need for a more thorough estimate of our waterpower resources and examined the question of reduction from theoretical to technical waterpower potential and from technical to economically developable power. We must learn more about our waterpower resources and how best to use them. How much will economic, social, political, and other considerations reduce them? The findings of the Select Committee and of the Ford Foundation show the urgent need for comprehensive and accurate inventories of our resources. The new inventory of hydroelectric power just completed for the Western States is a step in this direction.

Notable accomplishments and plans for development have taken place in the Northeast, the Northwest, the Colorado Basin (Upper Colorado River storage project), the Missouri River basin, California (where the State has adopted a long-range plan and initiated its construction), and in many parts of the South and Southwest.

The trend to large installations continues in the United States, as elsewhere. The John Day project in construction on the Columbia will have a 3,105-MW powerplant, and an installation of 4,760 MW has been suggested at Rampart Canyon on the Yukon River in Alaska. At Rampart Canyon a dam 500 feet high and a reservoir with an area of 10,700 square miles (larger than Lake Erie's 9,940 square miles and five times larger than Lake Kariba's 2,000 square miles) are contemplated.

The largest powerplant in the Western World was completed last year at Niagara Falls, N. Y. It is the Robert Moses Niagara Falls plant with installations totaling 2,190 MW (Moses, 1962). This project also pioneers further the pumped-storage field. Even though the Niagara is regulated by the Great Lakes, the nonuniform demand for electricity made it economically profitable to utilize, by pumped storage, up to 50,000 cfs of water not required by treaty to pass over the falls during night hours. Water is lifted as much as 100 feet and produces 20 to 28 MW of power as it flows back through the reversible units of the Tuscarora pump-generating plant. The pumps and generators are located upstream from the Robert Moses Niagara Falls plant so that the pumped water is used by the reversible pump-generating sets and then dropped an additional 300 feet through the Robert Moses units (Chappin, 1961).

In the Pacific Northwest, Chief Joseph, Rocky Reach, Wanapun, Priest Rapids, McNary, John Day, and The Dalles dams on the main stem of the Columbia River were completed or placed under construction between Jan. 1, 1955, and Dec. 31, 1962. These projects are by both private and public builders. A number of sizable projects have also been completed on smaller streams throughout the Northwest.

Oroville Dam, now under construction on Feather River in California, will be the highest earthfill dam in the world and the highest of all dams in the United States. The dam will be 735 feet high, 6,800 feet long, and will contain about 80 million cubic yards of gravel, earth, and rock. This is a multiple-purpose project including flood control, waterpower generation, irrigation, domestic water supplies, conservation, and recreation. It is scheduled for completion in 1968 and will be an important unit in the planned diversion of water from northern California to the central and southern parts of the State (Cullen, 1962).

In the Colorado River basin the Bureau of Reclamation is currently constructing four very important dams in the upper basin. In downstream order these dams are Flaming Gorge on Green River, Curecanti on Gunnison River, Navajo on San Juan River, and Glen Canyon on the Colorado River. These dams are units in a 17-dam plan for the upper basin. Glen Canyon Dam, the largest of the 17, is 370 miles upstream from Hoover Dam in Arizona near the Utah-Arizona boundary. It will be 710 feet high, surpassed in height only by Oroville and Hoover among United States dams. The reservoir, Lake Powell, will have a capacity of 28 million acre-feet, almost as large as and second only to Lake Mead among United States reservoirs. Lake Powell will extend 186 miles up the Colorado and 70 miles up the San Juan River. In addition to its other considerable benefits, the lake will have great recreational value as it is in an outstanding scenic and recreational area. The lake will extend to the vicinity of the Rainbow Bridge National Monument and will make possible boat travel to Rainbow Bridge. The dam is scheduled for completion in 1964 (Cullen, 1962).

Pumped storage has made rapid gains in the United States as in other countries. McCormack (1962) described the Taum Sauk pumped-storage project now under construction in Missouri as one of the boldest hydroelectric undertakings of the early 1960's. The plant's peaking capacity of 350 MW will cost about $115 per kilowatt without transmission. Water for the lower reservoir will come from the East Fork of the Black River, Mo., the discharge of which is sufficient to fill the lower reservoir twice a year. This will compensate for leakage and evaporation. The upper reservoir has an area of 50 acres and a capacity of 4,000 acre-feet. To save right-of-way costs the reservoir was blasted out of the top of a 900-foot high mountain. Pumping head varies from 764 feet minimum to 875 feet maximum. The units are Francis pump turbines and constructed much like conventional Francis turbines except that the bearing grooving is designed to permit rotation in both directions. Automatic operation of Taum Sauk will reduce the cost of the power by a considerable amount, and the benefits from automatic operation will increase as time passes (McCormack, 1962).

Canada

Canada added about 210 MW to installations in 1961 (a low for the past 15 years) and about 310 MW were scheduled for completion in 1962 (Canada Water Resources Br., 1962). Investigations now in progress may substantially increase the potential estimates.

Canada is investigating the Yukon River and may divert its waters south through Atlin Lake to low valleys in British Columbia. An assumed development in four stages would eventually increase the project to 3,660 MW (Wardle, 1957).

The principal areas of activity in Canada are in the east and the west. Quebec has a plan that will add 4,500 MW during the 1960's. It will include Manicouagan reservoir (one of the world's largest at 114 million acre-feet), five powerplants, and a 650-foot buttressed dam with multiple arches. An underground powerhouse of 522-MW capacity will also be included (Eng. News-Rec. Sept. 8, 1960, p. 23). In Newfoundland work is underway on the Twin Falls project on the Unknown River, a tributary of the Hamilton River. The initial installed capacity of 90 MW was scheduled to go on the line in June 1962. The plant is to be run-of-river initially, but 12 feet of storage will be provided later in two large lakes in the Unknown River headwaters (Water Power, May 1960, p. 166).

In British Columbia work has started on the Portage Mountain site on the Peace River. The first power is scheduled to be available by 1968. The Duncan Lake, High Arrow, and Mica storage developments are being actively investigated in connection with the 1961 Columbia River Treaty (Canada Water Resources Br., 1962).

Costa Rica

In Costa Rica, construction of a 30-MW hydroelectric plant on Rio Macho will be financed by the World Bank. This project is planned for 1963 as the first of a three-stage development where an ultimate capacity of 90 MW is expected (Burz, 1958).

El Salvador

Installations estimated to be a little less than 20 MW at the close of 1954 had increased to 65 MW by 1957 and are scheduled to reach 80 MW early in 1962. The entire increase has been made at one plant, the Guajoyo, on the Rio Lempa. The project includes regulation of Lake Guija in the headwaters and a regulating dam and underground powerhouse at a downstream site where 15-MW units are being installed as required and as money is made available. The present capacity, reported to be 45 MW, ultimately will be 75 MW (Harza and Zowski, 1957). A new hydroelectric plant being planned at Lake Guija near the Guatemalan border will have an initial output of 15 to 20 MW (Eng. News-Rec., July 28, 1960, p. 49).

Honduras

No additional installations were put on the line in Honduras between 1955 and 1962, but construction of one plant on the Linde River is reported to be underway. Honduras plans to interchange electric power with El Salvador. This will be feasible because peak consumption hours of the two countries are different (Eng. News-Rec., July 28, 1960, p. 49).

Mexico

Mexico is making rapid progress in hydroelectric development. The Gingambato underground plant, with an installed capacity of 135 MW, was recently completed on Rio Tilostoc southwest of Mexico City. In comparison with waterpower plants being constructed in Canada and in the Pacific Northwest, the plants in Mexico are relatively small; however, one, the Mazatepec project, will have an ultimate capacity of 208 MW in four Pelton units. Head will be about 1,740 feet (Bier, 1959). Diablo Dam, a joint project with the United States, is now under construction on the Rio Grande 12 miles upstream from Del Rio, Tex. The power from the 40-MW plant will be divided equally between the two countries. Plans for hydroelectric power in Mexico include eight more dams on the Papaloapan.

In 1958 Mexico had 2,623 power plants of all types. Waterpower plants accounted for 45 percent of the total installed capacity (Water Power, Aug. 1959, p. 285). The States of Mexico, Pueblo, Veracruz, and Michoacan have about 50 percent of the country's electric-power installations.

The most notable project in Mexico is probably Infiernillo on the Rio Balsas. It will have an installed capacity of 600 MW in four 150-MW vertical axis Francis sets in its underground powerhouse. Average head will be 390 feet. Mexico's next largest plants are Apulco and Mazatepec, each with 208 MW installed (Eng. News-Rec., Mar. 15, 1962, p. 30).

Nicaragua

Nicaragua has a 50-MW powerplant under construction at the present time. Water will be diverted from an area of heavy rainfall in the tradewinds zone across the continental divide to the drier, more densely populated western region where the steeper Pacific slopes concentrate the head (Water Power, Sept. 1960, p. 332).

Panama Republic and Canal Zone

Reports on developments are conflicting but seem to indicate that the Republic has about 48 MW installed, (only 4 MW hydroelectric), and the Canal Zone has installations of about 90 MW (61 MW hydroelectric). The United Nations Statistical Yearbook for 1961 (p. 292) gives 73 percent hydroelectric to fuel fired generating installations in the Canal Zone. Panama has obtained a loan from the World Bank to develop the 4-MW Yeguada hydroelectric plant to serve the central provinces (Water Power, Dec. 1962, p. 462).

West Indies

Installed capacities, in megawatts, of hydroelectric plants in the West Indies are:

Cuba	3
Jamaica	13
Martinique	9.6
Puerto Rico	109.2
St. Thomas	.2

The Dominican Republic is continuing work on two hydroelectric projects and plans for a third have been completed. The information on these three plants—the Tavera, the Nizao, and Las Damas—was obtained from recent announcements in the periodical "Water Power." Precise information is unavailable as to installed capacities planned for the various plants, but the plants are probably the biggest engineering projects yet undertaken in the Republic. In addition to the waterpower developed the projects will irrigate some 247,000 acres and provide work for a large number of persons.

Work is progressing at Richmond on St. Vincent Island, on a scheme that will double the present generating capacity of the island. The capacity is not given (Water Power, Feb. 1962, p. 47).

SOUTH AMERICA

The installed capacity of all plants (fuel and hydroelectric) in South America was 10,300 MW in 1960. Of this, about 50 percent was in developed water-power plants. The principal activity in connection with waterpower development in South America since our last report (Young, 1955) has been in Brazil, but other countries have made substantial gains. Installed water-power plants in Argentina, for example, are now four times those of Jan. 1, 1955, and the growth rate is 7.56 per 10-year period. Chile, Colombia, Peru, and Uruguay have conducted extensive investigations and have plans for substantially increasing hydroelectric generation.

Argentina

A 12-MW hydroelectric plant is under construction on Rio Sali near San Miguel de Tucaman by British companies. The project is scheduled for completion in 1965 and will include a dam 225 feet high by 1,400 feet long (Water Power, Mar. 1962, p. 86). A planned project on the Rio Negro calls for installations of 1,000 MW between 1965 and 1970 (World Power Conf., 1962, reprint 149 I.2/19).

Bolivia

Demand for power exceeds supply in Bolivia, especially in the vicinity of La Paz, but plans based on a United Nations study provide for increasing the supply (Water Power, Aug. 1962, p. 296).

Table 11.—Installed capacity of hydroelectric plants, 10-year growth ratio, hydroelectric as percent of total generating installations, and estimated gross theoretical power of developed and potential sites of South America

[U, unknown or not found]

	Installed capacity[1] (approx, in MW)	10-year growth ratio (normal = 2 Jan. 1, 1955 = 1)	Percent of total (approx)	Estimated gross theoretical potential (MW)	
				Q95	Arithmetic mean
Argentina	400	5.87	10	4,050	30,000
Bolivia	110	1.44	70	2,700	22,500
Brazil	3,850	1.80	80	15,000	180,000
British Guiana	6	U	33	2,700	15,000
Chile	688	1.43	52	9,500	26,600
Colombia	585	1.98	55	4,050	75.000
Dutch Guiana	U	U	U	825	7,500
Ecuador	40	3.02	32	1,500	26,250
French Guiana	U	U	U	U	U
Paraguay	[2]4	U	U	2,100	7,500
Peru	450	2.16	60	4,800	41,250
Uruguay	236	2.03	55	300	2,250
Venezuela	500	11.70	6	3,225	37,500
Total	6,865	----	--	50,750	471,350
Weighted avg	-----	2.08	50	------	-------

[1]As of Dec. 31, 1962.
[2]United Nations (1961) lists all plants as thermal.

Brazil

Industrial development in Brazil has made it necessary to expand the country's power-production capacity, and much activity in waterpower planning and development has taken place since 1955. The Brazilian National Committee of the World Power Conference recently described Brazil's power developments and indicated that installed capacity is expected to reach 8,000 MW by 1965 (Water Power, Jan. 1961, p. 39).

The most spectacular waterpower developments are the Tres Marias and Furnas multiple-purpose projects. The Tres Marias dam is an earthfill structure 8,856 feet long and 230 feet high on the Sao Francisco River. The reservoir is 93 miles long and stores 16,214,200 acre-feet of water (Water Power, Dec. 1959, p. 446). The project's principal purposes are irrigation (in the Sao Francisco River Valley), power, flood control, and navigation. The discharge of the river varies greatly and regulation is required to furnish irrigation water. The Tres Marias plant has a planned capacity of 520 MW, and it will be possible to increase the capacity of the Sao Paulo plant downstream from 600 to 1,000 MW (Water Power, Dec. 1959, p. 445).

Downstream from the area irrigated by the Tres Marias multiple-purpose project, the Sao Francisco River passes over a series of rapids and falls representing a gross head of about 660 feet. The Paulo Afonso drop alone contributes 295 feet. The river is flowing at 741,600 cfs but splits into many small falls, which makes it difficult to concentrate a large volume of water for power development. The present plant at the Paulo Afonso drop has three 60-MW units installed under a head of about 270 feet (Gravert, 1960).

Three 9,000-kw vertical Francis generating units are being installed at a reservoir built to create a lake for the city of Brazilia. The plant will operate in conjunction with the larger stations at Cachoeira, Dourada, and Tres Marias (Rettig, 1960).

The Furnas development on the Rio Grande, a tributary of the Parana, is the main project in an area that includes both Rio de Janeiro and Sao Paulo. The Furnas dam is earth and rockfill and raises the water surface 302 feet. When completely installed, the plant will have a capacity of 1,100 MW in eight units of 137.5 MW each. The reservoir can regulate the river to a minimum discharge of 30,970 cfs. Eighteen plants are planned for the Rio Grande—13 of them downstream from the Furnas reservoir. The regulated stream will have a potential power capacity of 7,000 MW (Water Power, Nov. 1958, p. 426).

A fourth important development in Brazil is Salto Grande on the San Antonio River. The San Antonio drains an area north of Rio de Janeiro and empties into the Atlantic Ocean. This project takes advantage of a natural drop of 508 feet in a 20-mile streatch of the river near the junction of Rio Guanhaes. The site has an estimated potential capacity of 100 MW and the total of the river system is estimated at 350 MW (Water Power, Nov. 1956, p. 417). Separate dams on the San Antonio and Guanhaes Rivers are interconnected by a tunnel, and the water is carried through a second tunnel to a point on the San Antonio River downstream from the Salto Grande. The first stage includes two units with generators rated at 25 MW each under a head of 312 feet. Two additional units similar in nature are to be added in the second-stage development.

British Guiana

British Guiana and neighboring parts of the South American continent have considerable potential waterpower.

The Potaro River basin, with many peaks reaching altitudes of 6,000 feet, reportedly receives the highest rainfall of northeastern South America (Water Power, Jan. 1958, p. 20). Tropical rain falling principally in May, June, and July is followed by a dry period lasting until November or December. There is a second but less reliable rainy season in December or January. At Kaieteur Falls the Potaro descends 740 feet in a spectacular cascade. Discharge averages about 8,000 cfs, but a low of 600 cfs has been recorded, and worse droughts may occur at frequent intervals. A power development downstream from the falls, where a head of 250 feet could be created by a dam, has been investigated (Deleva and Bartholomew, 1958).

Chile

The developed power shown in table 11 includes 48.6 MW from the recently completed Pullinque plant (Water Power, Jan. 1963, p. 27). The potential power estimates are from a report of the World Power Conference (1962, reprint 153 I.2/21), which stated that 23,700 MW can be installed. Another recent study places the hydroelectric potential at 20,300 MW for average discharge. The 1954 estimate (Young, 1955) was 18,600 MW.

Chile leads all Latin American countries in per capita consumption of electricity—600 kwhr (killowatt hours) per capita per year. Plans to 1972, if followed, will more than double present capacity, and the planned developments are expected to produce power at less cost than power produced by plants now in operation (Salazar and Bennett, 1960). By 1972 it is expected that the country will have a completely interconnected transmission grid. This will permit utilization of the different river regimens—some being snow fed with low discharge in winter, others being pluvial with high winter flow and low summer or autumn flow. Storage is expensive in Chile except where natural lakes can be utilized.

In 1939 the government created a corporation for planning, promoting, and financing new industry. A subsidiary of this corporation was given the special job of planning electric supply. In 1943 this unit became a separate corporation named Empresa Nacional de Electricidad (ENDESA). ENDESA was responsible for 63 percent of the 1951 installations.

The most spectacular plan now in development is on the Rapel River 75 miles southwest of Santiago. World Bank funds are available for a project of 280-MW capacity, including a dam 300 feet high and a reservoir with a capacity of 570,000 acre-feet. Two of the four planned 70-MW generators are scheduled to be put on the line in 1964 (Water Power, Feb. 1960, p. 47).

Colombia

The Laguneta project on the Bogata River, which has been under consideration since the early part of the century, was developed between 1955 and 1963. This project diverts water at the Salto I plant tailrace and carries it in a concrete-lined tunnel 7,216 feet long to a power drop of about 951 feet. The powerhouse contains four 20-MW generating sets driven by vertical turbines. A World Bank loan has been obtained to add Salto II, which is scheduled for completion in 1964 with 66 MW installed. A 26 MW plant, Charquito II, is planned for the future (Ospina and Montana, 1959). The principal power markets in Colombia are in the areas around the four largest cities, Bogata, Medellin, and Cali, located in mountainous areas where hydroelectric powersites are available, and Barranquilla on the Carribean where oil-fired steam plants are used because of the distance to the Andes (Ospina, 1956).

The Anchicaya project serves the Cali area. Begun in 1954, its first units, two 12-MW sets, were installed in 1955. Two additional 20-MW units were put in commission in 1956, providing an installed capacity of 64 MW. The Anchicaya River, which drains about 290 square miles, discharges an average of 3,178 cfs, a minimum of 706 cfs, and a maximum of 63,566 cfs. The Anchicaya dam provides pondage only. A pressure tunnel 20 feet in diameter carries the water to a surge tank and drop to the powerhouse. A recent loan from the World Bank will permit installation of additional power for the Cali area, and another new plant, to be completed in 1964, will have a full capacity of 120 MW in four units. The project will include a dam on Calima River 37 miles northwest of Cali. The reservoir will have a capacity of 320,000 acre-feet, and there will be an underground powerhouse (Water Power, Aug. 1960, p. 293). The Medellin area, it is planned, will have additional hydroelectric installations with total capacity of 246 MW in service on the Guadalupe and Nare Rivers by 1964. The present installations are at the Troneras dam on the Guadalupe River (96 MW) and presumably were put in operation in 1961. Water is diverted from the Concepcion and Tenche Rivers upstream from Troneras dam (Water Power, Aug. 1959, p. 286). One plant (Guadalupe) has a 1762-foot head.

Manizales, an area deficient in power not far from Medellin, has recently had its power-generating capacity doubled by the addition of a 26.6-MW plant (La Esmeralda). This is one of several planned extensions to the Chinchina and Campoalegre Rivers (Water Power, Apr. 1959, p. 122).

Dutch Guiana (Surinam)

The Aluminum Co. of America has ordered six generating units of about 35-MW capacity each for the Surinam River. An earth dam 175 feet high will create a lake with an area of about 580 square miles, which, as a "multiannual" reservoir, will distribute discharge almost uniformly over the whole year (Water Power, Feb. 1960, p. 46).

Ecuador

A hydroelectric development now being planned will supply the capital, Quito, with an additional 40 MW (Water Power, Oct. 1958, p. 366).

Peru

Peru was actively developing waterpower between 1955 and 1962. In the Lima-Callao area the 30-MW Gino Biaanchina-Huampani plant was added on the Rimac River and work is underway on a 240-MW plant, Grand Central de Huinco on the Santa Eulalia River. The schedule calls for the first 60-MW unit to be in service in 1963 (Eng. News-Rec., July 28, 1960, p. 44). Diversion of water from the east slope rivers and lakes to the Santa Eulalia River on the west slope is included in the plan (Water Power, Oct. 1960, p. 372).

A team of Electricite de France Engineers, conducting a study for Peru, divided the country into three main climatic zones: (1) the coastal strip—62 miles wide, highest altitude 19,680 feet, almost no precipitation; (2) the high Andean plateau east of the Cordillera—abundant precipitation (tributaries to the Amazon); (3) the thickly wooded plain of the Amazon—damp and tropical region. The study finds that Peruvian rivers have their high-water periods at the same time. This situation rules out the possibility of balancing discharges of different rivers. The wide range in altitude and the high rate of minimum discharge in the Amazon basin make Peruvian water resources economical to harness, however. The study group listed three sites as particularly suited for hydroelectric development: (1) the Machu-Picchu where the Vilcanota River can be shortened from 9.3 to 1.2 miles by a tunnel to provide a head of 1,148 feet and an output of 100 MW; (2) the Mantaro River east of Lima where a 9.3-mile tunnel can create a head of 3,280 feet and generate 1,000 MW; and (3) the Maranon River where a dam about 180 feet in height would create a lake capable of insuring a constant discharge of 240,138 (cfs) which could produce 3,000 MW. Work on the first two suggested developments is planned for the near future (Mary, 1959). The cheap power will permit greater diversification of industry.

Uruguay

Hydroelectric generating capacity was not increased in Uruguay between 1950 and 1957. Work is underway on the Rincon de Baygorria plant, which will have a capacity of 102.6 MW on the Rio Negro. Two plants are to be built downstream from the Baygorria plant—Peso del Puerto and Yapeyu (Water Power, July 1959, p. 246). The Peso del Puerto plant will be 68 miles downstream from Baygorria and will have a machine hall for four 44.75 MW generators driven by Kaplan turbines. A joint Argentino-Uruguayian development on the Rio Uruguay, the Salto Grande project, will include a dam to create a head of 90 feet and an installed capacity of 1,400 MW in twenty 70-MW Kaplan units (Water Power, May 1960, p. 208).

Venezuela

A 100-foot high by 9-mile long dam was built in record time on the Guarico River 190 miles south of Caracas. The reservoir stores 1,500,000 acre-feet (Eng. News-Rec., Sept. 29, 1956, p. 51). Completion of Macagua No. 1 plant (370 MW) on the Caroni River ends the first of a four-stage development plan for which installations may total 8,000 MW. The Caroni River, an Orinoco River tributary, reportedly possesses one of the largest hydroelectric reserves in the world (Water Power, Oct. 1962, p. 381).

The Orinoco and Caroni drain the west and north sides of the Guiana plateau, where average annual rainfall is very high but where excessively wet and dry seasons occur. Storage or a balancing interconnection will be necessary to achieve the maximum development of its waterpower resource.

AFRICA

Political unrest and attendant general turmoil have retarded water resources development in Africa, but the momentum built up after the Second World War carried on into this period in some parts of the continent. Noteworthy in this category are a project near Insangila on the Congo River, the power facilities installed at Aswan Dam on the Nile, and the Kariba gorge development on the Zambezi.

Table 12.—Installed capacity of hydroelectric plants, 10-year growth ratio, hydroelectric as percent of total generating installations, and estimated gross theoretical power of developed and potential sites of Africa

[U, unknown or not found. E, estimated]

	Installed capacity[1] (approx, in MW)	10-year growth ratio (normal =2 Jan. 1, 1955 = 1)	Percent of total (approx)	Estimated gross theoretical potential (MW)	
				Q95	Arithmetic mean
Algeria	180	1.13	23	225	6,000
Angola	120	22.0	U	4,250	78,300
Basutoland	U	U	U	[2]310	490
Bechuanaland	U	U	U	22	3,730
Burundi	U	U	U	U	U
Cameroun Federation	159	11.4	90	[2]4,800	[2]28,700
Canary Islands[3]	1.1	U	U	U	U
Central African Repub	3.5	U	2	[2]3,500	[2]13,800
Congo	763	2.9	90	97,000	180,000
Dahomey	U	U	U	600	2,240
Egypt	365	54	35	375	900
Ethiopia	8.5	1.13	60	4,250	35,000
French Somaliland	U	U	U	U	U
Gabon[4]	18.6	U	60	[2]6,000	[2]21,900
Gambia	U	U	U	U	U
Ghana	42	U	41	1,500	7,500
Guinea	20	2.71	U	[2]500	[2]8,000
Ivory Coast	[2]20	U	U	[2]500	[2]7,300
Kenya	26	1.03	31	1,500	16,800
Liberia	[2]3	U	16	4,250	7,500
Libya	U	U	U	0	200
Malagasy	24	1.82	44	[2]14,300	[2]80,000
Mali	1	U	U	[2]750	[2]4,400
Mauritania	U	U	U	200	2,500
Mauritius	[2]13.6	1.65	18	20(E)	100(E)
Morocco	[2,5]320	1.13	80	300	1,500
Mozambique	70	U	66	3,750	15,000
Niger	U	U	U	500	12,000
Nigeria	20	1.04	11	9,500	22,000
Portuguese Guinea	U	U	U	0	150
Reunion	[2]3.5	U	U	20(E)	100(E)

Table 12.—Installed capacity of hydroelectric plants, 10-year growth ratio, hydroelectric as percent of total generating installations, and estimated gross theoretical power of developed and potential sites of Africa--continued

[U, unknown or not found. E, estimated]

	Installed capacity[1] approx, in MW)	10-year growth ratio (normal = 2 Jan. 1, 1955 = 1)	Percent of total (approx)	Estimated gross theoretical potential (MW)	
				Q95	Arithmetic mean
Rhodesia and Nyasaland	810	45.3	70	[2]4,680	22,500
Ruanda	U	U	U	U	U
Senegal	U	U	U	500(E)	[2]5,500
Sierra Leone	U	U	U	2,000	3,750
Somali Republic (Somalia)	U	U	U	0	300
South Africa	[2]5	U	U	335	10,000
South-West Africa	U	U	U	150	1,500
Spanish Guinea	U	U	U	750	3,000
Spanish West Africa	U	U	U	260	750
Sudan	U	U	U	750	20,000
Swaziland	U	U	U	[2]700	U
Tanganyika	40	2.50	65	3,000	26,000
Tchad	U	U	U	1,000(E)	[2]4,300
Togo	U	U	U	100(E)	[2]600
Tunisia	27	4.96	19	30	380
Uganda	121	2.40	90	3,000	15,000
Upper Volta	U	U	U	500	15,000
Total	3,185	----	--	176,677	684,690
Weighted avg	----	4.00	60	-------	-------

[1]As of Dec. 31, 1962.
[2]From World Power Conf. (1962).
[3]Installations in Santa Cruz Province.
[4]Considerable potential due to heavy rainfall and large rivers.
[5]300 MW in 1960, plus estimated 20 MW growth since then.

Algeria

Work has been in progress since 1955 on the Oued Djen-Djen in the Kabylia Mountains. A multiple-arch dam at Erraguene, less than 9 miles from the sea, creates a 162,000 acre-foot reservoir at an altitude of 1,970 feet. A power station at the toe of the dam has 14.4 MW installed capacity and a 6.2-mile tunnel which can carry 70 cfs discharge to the underground Mansouria plant on the coast (La Tech. de L'Eau, 1962, p. 43).

Angola

The Cambambe plant on the Cuanza River was put in service in December 1962. Complex foundation problems were encountered, and work was suspended when the dam was about 100 feet lower than originally planned. The reduced head decreases the capacity of the planned 65-MW sets, two of which are now in service, to 46 MW each. This is a multiple-purpose project and will furnish water for irrigation on the lower Cuanza and Bengo Rivers (Water Power, July 1962, Mar. 1963, p. 272). South West Africa has a project planned for the Kunene River that will affect Angola.

Congo

When the Congo's ties with Belgium were broken, a gigantic development was underway near Insangila on the Congo River. The plan called for developing 25,000 MW with a head of 425 feet. The river flow is 700,000 cfs (Water Power, Jan. 1958, p. 2).

Egypt

Installation of generators at the First Cataract Aswan Dam 600 miles south of Cairo was the most noteworthy hydroelectric power development in Egypt between 1955 and 1962. The original Aswan Dam with a storage reservoir of about 800,000 acre-feet was completed in 1902. Its success in supplying needed regulation led to demands for more storage. The dam was heightened in 1912 and in 1933. It is 115 feet above the riverbed, is 6,983 feet long, and stores a little more than 4 million acre-feet of water.

Power development has been contemplated since the construction of the first dam, but was not realized until 1960 when the power station was in partial operation. Head for power development ranges between 31 and 110 feet, and available power fluctuates in approximately the same proportion—94 to 300 MW based on an average normal year (Water Power, Dec. 1961, p. 466). The station contains seven Kaplan turbine generating units of 47 MW maximum capacity each and two sets of 11.5 MW maximum capacity (Water Power, Jan. 1961, p. 1).

Progress has also been made on the High Aswan Dam planned for a site upstream from the Aswan reservoir. Among the benefits to accrue from the High Aswan Dam will be the elimination of floods on the Nile River, addition of some 30 percent to total irrigated land, production of power from 16 turbines of 120 MW capacity each, and the doubling of the present power power potential of the downstream Aswan Dam (Eng. News-Rec. Feb. 9, 1956, p. 44).

The possibility of utilizing evaporation in the development of waterpower has received considerable attention in Egypt in recent years. One plan would dam the Red Sea at both ends, allow evaporation to lower sea level (12 ft per yr according to Hassan), and eventually admit 1½ million cfs to produce 50,000 MW (Hassan, 1961). Another similar scheme would admit water to Egypt's Qattara Depression (440 feet below sea level) by one of several means. One method would combine pumped storage with diversion in a manner that would assure 100.2 MW and make as much as 345 MW available when the pumps are not running (Gohar, 1961).

Ethiopia

The developed and potential estimates shown for Ethiopia in table 12 include those for Eritrea.

No information on new installations in Ethiopia has been noted since 1955 but studies and plans have been made. French research engineers (Societe Grenobloise d'Etude et d'Application Hydraulic) are continuing the study of the Hawash River and will recommend a scheme for optimum utilization of the water, including regulation for hydroelectric development and irrigation (Water Power, Dec. 1961, p. 461). Two plants are in operation on the Akaki River, a Hawash tributary. One of these is at Gageia dam and the other at Abba Samuel. The Coca project planned for a site further upstream on the Akaki will have a reservoir of 932,000 acre-feet (Water Power, Oct. 1958, p. 400). Lake Assal near Somalia and the Red Sea occupies the bottom of a large basin below sea level where generation of power from sea water would be technically possible.

Ghana

Ghana was listed as Gold Coast by Young (1955). No waterpower developments are known to have been completed since 1955, but the Akosombo project is underway on the Volta River 70 miles inland. The project includes a 370-foot high rockfill dam, a 120-million-acre-foot reservoir, and a powerplant with four Francis turbine sets of 128 MW each under a head of 213 feet. Ultimate capacity is to be 868 MW (Eng. News-Rec., June 1, 1961, p. 24). The first stage may be near completion. The power will be used by an aluminum factory to be built at Akuse near the dam. A downstream plant of 600 MW is also being planned. The U.S.S.R. reportedly agreed to finance a project at Bui on the Black Volta. The station is to have a capacity of 200 MW with all equipment supplied by the U.S.S.R. (Water Power, Apr. 1961, p. 127).

Ivory Coast

When the country became an independent nation in the French community in 1958 a 19.2-MW project on the Ayame in the Bia River basin was under construction. This was to include a dam and power development with a head of 62 feet (Water Power, Mar. 1959, p. 119). Work on the plant, begun in 1956, presumably has been completed.

Kenya

No developments are known to have been achieved in Kenya since 1955. The bulk of Owens Falls hydroelectric output is imported from Uganda. In 1958 the demand was for 14 MW and increased to 22 MW by 1961. The Uganda Electricity Board has agreed to supply the Kenya Power Co. a maximum of 45 MW (Water Power, May 1958, p. 163). The East African Power & Lighting Co. is planning the Seven Forks development (no details available) (Water Power, Sept. 1962, p. 336).

Liberia

United Nations world-energy summaries reported 10 million kwhr produced by hydroelectric stations in both 1955 and 1958. If there has been no increase in installations the plant factor was about 39 percent for 3 MW.

Mozambique

The Chicamba Real development, which will supply energy to Manica and Sofala, is underway. Oliveira Salazar Dam in this project will create a reservoir of 353,000 acre-feet capacity, and a 35-MW powerplant will be installed in the future (Water Power, June 1962, p. 250).

Nigeria

The feasibility of developments on the Kaduna River at Shiroro Gorge (Water Power, Aug. 1957, p. 281) and on the Niger River near Jebba are being investigated, and a combination flood-control, hydroelectric, and irrigation project on the Niger River at Kainji is planned. The main dam for the Kainji project is to be completed in 1968 with a 70-MW plant. Plans call for 980 MW by 1980 (Water Power, Jan. 1963, p. 4).

Rhodesia and Nyasaland

Several units were installed at Kariba gorge soon after January 1, 1962 and total installations in the federation increased to an estimated 812 MW by April 1962.

The world's second largest manmade lake, at Kariba gorge on the Zambezi River, has been put in service since 1955. Kariba Dam is about 300 miles downstream from Victoria Falls, and the new lake extends 170 miles upstream. It is 40 miles wide in places, covers about 2,000 square miles, and has a capacity of about 130 million acre-feet—four times that of Lake Mead (Gibb, 1958). The first powerhouse (an underground installation) was completed with 400 MW in four units in March 1962. Plans for the second stage (a powerhouse on the opposite side of the river) scheduled for 1970 have been temporarily shelved (Water Power, June 1962, p. 210).

A development is planned at Nkula Falls on the Shire River, which will produce hydroelectric power and also stabilize the levels of Lake Nyasa (Water Power, Oct. 1960, p. 373). Work on this project was scheduled for early 1962 but a delay now seems likely. The Zambezi, Shire, Sabi, Luapula and Limpopo Rivers are the federation's most important power streams (World Power Conf., 1962, reprint 24 I.2/24).

South Africa

Very little was seen in the press about completion of projects in South Africa. However, an extensive development plan to be carried out in six phases will include construction of 20 hydroelectric stations on Fish River and downstream on the Orange River to the Atlantic coast. The total capacity of the stations is projected as 177 MW, including power for pumping irrigation water. There will be three large dams on the Orange River as follows: Ruigte, 390 feet high, capacity 1,300,000 acre-feet; Kloof, 395 feet high, capacity 1,280,000 acre-feet; Torkay, 205 feet high, capacity 210,000 acre-feet (Water Power, June 1962, p. 244, Eng. News Rec. Apr. 25, 1963, p. 49). Installations have been made in Cape Province, Transvaal, and Natal, some of them in 1958, 1959, and 1960 (Wilson, 1962).

South-West Africa

No recent completions were noted in this country. However, investigations are in progress on two projects on the Kunene River. The upstream dam would be 20 miles inside Angola and the second at Ruacana Falls on the boundary line between the two countries (Water Power, June 1962, p. 211).

Sudan

Roseires Dam on the Blue Nile has top priority among projects planned in Sudan. This upstream reservoir will store 2,400,000 acre-feet of water. Among the benefits to agriculture that will accrue from it will be increased yield on the Managil and Gezira cotton plantations. Work is underway at the Sennar Dam on the Blue Nile to install two 7.5 MW Kaplan sets (Water Power, Mar. 1960, p. 59). A third project the Khashm el Girba on the Atbara, is being planned in connection with relocation and resettlement of Sudanese displaced by backwaters from the High Aswan Dam (Eng. News-Rec., May 19, 1960, p. 86).

Tanganyika

Two 10.5-MW vertical Francis sets for the Hale project on the Pangani River are scheduled to go into operation early in 1964 (Water Power, Dec. 1961, p. 462).

Tunisia

There has been considerable activity in water-resource development in Tunisia since 1955. Most Tunisian developments are multipurpose with water-power usually secondary. A development at the junction of the El Lil and Lebgu Rivers created a lake where one had existed in recent geological times. A buttress dam was chosen because of instability of the damsite (Water Power, Sept. and Oct., 1956, p. 377).

Uganda

Most energy used in Uganda, which became Africa's 33d independent nation on October 10, 1962, is generated by a 120-MW plant at Owens Falls, where 169,500,000 acre-feet of manmade storage capacity was added to Lake Victoria before 1955. It is reported that only about one-half of the station's capacity is presently being used. This includes the 22-MW block now sold to Kenya (Water Power, May 1961, p. 170). Transmission of power to remote areas is a problem in Uganda, and plans for exchanging power with some existing mining plants are under consideration as well as a plan to develop in two stages a 3-MW run-of-river project on the Muzizi River, which flows over a 1,400-foot escarpment into Lake Albert. The capacity of the plant can be increased to 7.5 MW if desired (Water Power, Oct. 1958, p. 365). Most areas of the country are scheduled to have electricity by 1964 (Water Power, Aug. 1962, p. 295).

ASIA

Ridges 25,000 feet and valleys 10,000 feet in altitude radiate from the Pamir Knot "roof of the world" dividing Asia into six natural regions: central, northern, eastern, southeastern, southern, and southwestern. Either because of great relief, immense size, heavy rainfall, or combinations of these, all these regions are endowed with great waterpower potential.

Central Asia receives little rainfall but its snow-capped mountains serve as reservoirs for distributing the runoff throughout the year, and the stream gradients create waterpower sites with high heads.

Northern Asia, the largest natural region, has sites where immense waterpower developments could be realized, especially in the basins of the Irtysh, Ob, Yenisei, Nizhnyaya, and Lena Rivers. Lake Baykal on a tributary of the Yenisei is the largest fresh-water lake in northern Asia and the deepest lake in the world. The Russians have elaborate plans for developing the waterpower of this region.

Eastern Asia includes Japan, Korea, China, and Formosa. Japan is one of the leading countries in the world in amount of waterpower developed. Japan also developed many powersites in China and Korea. China has plans for developing much waterpower but little is known of the progress made. The Nationalist

Chinese on the island of Formosa depend heavily upon waterpower. Plants constructed there by the Japanese have been rebuilt and enlarged. New plants are also being built and additional ones planned.

Table 13.—Installed capacity of hydroelectric plants, 10-year growth ratio, hydroelectric as percent of total generating installations, and estimated gross theoretical power of developed and potential sites of Asia

[U, unknown or not found]

	Installed capacity[1] (approx, in MW)	10-year growth ratio (normal = 2 Jan. 1, 1955 = 1)	Percent of total (approx)	Estimated gross theoretical potential (MW)	
				Q95	Arithmetic mean
Afghanistan	111	5.14	95	525	7,500
Burma[2]	[3]7.5	U	U	3,750	93,750
Cambodia	[4]U	U	U	U	U
Ceylon	55	1.85	57	[5]375	1,475
China	U	U	U	40,000	220,000
Formosa	560	1.80	58	750	2,250
India	2,450	3.79	33	[5]31,000	86,250
Iran	116	U	U	225	3,000
Iraq	U	U	U	U	1,125
Israel	U	U	U	U	150
Japan	14,000	2.04	53	9,000	18,750
Jordan	U	U	U	U	U
Korea (North and South)	1,350	U	U	2,250	3,750
Laos	U	U	U	U	U
Lebanon	65	U	U	U	U
Malaya	40	U	U	[5]316	[5]548
Nepal	U	U	U	U	U
Netherlands New Guinea	4	U	U	7,875	52,500
Pakistan	[5]346	8.40	41	[5]6,560	15,000
Philippines	350	5.87	35	1,500	12,750
Saudi Arabia	U	U	U	U	1,125
Syria	U	U	U	U	U
Thailand	30	U	U	3,000	15,000
Tibet	7.5	U	U	U	U
Turkey	500	44.4	35	1,200	16,730
U.S.S.R	(6)	(6)	(6)	48,000	[7]325,000
Vietnam Republic	.15	U	U	4,500	[8]67,500
Total	19,992	---	--	160,826	944,153
Weighted avg	------	2.13	50	-------	-------

[1]As of Dec. 31, 1962.
[2]No known recent developments.
[3]Generating capacity from all sources is 256 MW.
[4]Generating capacity from all sources is 21 MW.
[5]From World Power Conference (1962).
[6]See U.S.S.R. in Europe.
[7]Available 50 percent of time.
[8]Includes Laos.

Southeastern Asia includes the area from Indochina to Burma and the Philippine Islands. The mountains are not as high in this part of the continent, but heavy rainfall and considerable topographic relief combine to make it rich in potential waterpower sites. Only a small proportion of the potential has been utilized.

Southern Asia (the Indian subcontinent), with some of the highest altitudes and some of the heaviest rainfall areas of the world, has great power potential. Unfortunately, the centers of population where power is in greatest demand are at long distances from the better powersites.

Southwestern Asia is a dry region with only a few districts that can be classed as well watered. The Tigris and the Euphrates are the most important rivers in the area, but many streams in the Hindu-Kush can be developed for waterpower production when the demand arises.

Present advances in sanitation and medicine and the continued high birth rate in most Asian countries are contributing to a population explosion that is forcing the Asian governments to accelerate industrial development. As part of this acceleration, water-resource developments, including waterpower, are being planned and carried out at an unprecedented rate.

Afghanistan

Afghanistan has an area of about 250,000 square miles, almost three-fourths of it included in the Hindu-Kush Range. The mountains reach heights of about 25,000 feet along the Pakistan border. Even though the climate is dry, Afghanistan has immense potential water-power because of the regulating effect of the snow in the mountains and the great variation in relief of the land. The principal rivers are Helmand, Amu Darya (Oxus), Kabul, and Hari Rud. Only a very small proportion of the waterpower resource has been developed. Plans for developments date back to the 1930's, but it was not until the 1950's that progress went beyond the planning stage. In 1951 work was started on the Sarobi power project on the Kabul River. The first-stage development includes a small reservoir, a single pressure tunnel, and two turbines rated at 11.8 MW. Each turbine uses 971 cfs under a net head of 157 feet (Water Power, Apr. 1958, p. 142). In a second-stage development another tunnel will be driven and the plant capacity increased to 43 MW.

Ceylon

The most important hydroelectric development in Ceylon is a two-stage scheme including a reservoir and powerplant on Kehelgamu Oya and a diversion at the powerhouse tailrace to the Maskeliya Oya. Each powerhouse has 25 MW installed. The average annual rainfall at the dam (Norton Dam) is about 220 inches—the highest on the island. A southwest monsoon brings most of the rainfall during a 5- or 6-month period. Flow variation is great and storage is provided in the Norton and Castlereagh Reservoirs on the Kehelgamu Oya. The Castlereagh Dam is a mass concrete gravity structure. The reservoir volume at the spillway level is 49,000 acre-feet. The first-stage plant contains three 8,333 kw alternators driven by double-jet Pelton turbines operating under a normal head of 1,500 feet (Water Power, Sept. 1956, p. 346). Since the inauguration of the first 25-MW plant in 1950 hydroelectric energy has been the principal source of power on the island, with steam plants acting as standby for peaking purposes. The demand for electric energy has increased sharply and more hydroelectric developments are needed.

China

The potential power estimates shown for China in table 13 are about 40 percent of the gross theoretical estimate of Teng Tsai-shou (1957). This estimate assigned a grand total of 544,000 MW at average discharge. It included Tibet, Taiwan, Hainan, and Lwan Ho. Potential was computed by river sections for gross head and 100 percent efficiency using the following basic formula: Kilowatts = 9.8H times $\frac{Q1 + Q2}{2}$ where the head (H) is in meters and the flow (Q) is in cubic meters per second. To provide for the hyperbolic shape of the river profile in the headwaters, a coefficient of 0.5 was used to modify the result. For the section of the river at its origin where $Q_1 = 0$ the formula is kilowatts = 2.45 (Q^2H) to preclude overestimation. The study utilizes records from a great many gaging stations, and if the estimates can be appropriately reduced to eliminate river reaches that are obviously not developable, it should be quite reliable. An estimate that about 40 percent of the gross potential is technically feasible seems appropriate for the time being.

China has reportedly put much effort into hydroelectric and water-conservation projects in recent years and has restored many plants damaged during the war. Hydroelectric plants that have been commissioned are Qwanting near Peking and Kutien in Fukien province. Investigational work is reported to have been carried out on the major rivers (Water Power, Feb. 1957, p. 60). Sanmen Gorge Dam on the Yellow River probably is the most significant waterpower development by China during the period 1955-62. The Sanmen Gorge Dam is 330 feet high and 3,198 feet long, and the reservoir reportedly has a capacity of 53 million acre-feet.

Formosa

The Nationalist Chinese Government is installing waterpower plants as fast as possible to meet the demand for power in Formosa (Taiwan). The 177 MW of hydroelectric power installed by the Japanese had dwindled to only 33 MW in 1949 when Taipower took over the system. The former capacity was quickly restored, and larger installations at existing developed sites and at new sites have increased the installed capacity at hydroelectric plants to 560 MW.

In line with the trend of most power developments since World War II, those on Formosa are on a large scale and most of them include regulating reservoirs. Many powerhouses are underground. One of these underground plants, the Tienlun plant, replaces one that was completely buried by an earthquake and floods in 1943. Twenty-one MW were installed in the Tungmen plant in 1955. In 1959 the Lungchien plant on the same river was inaugurated. It is notable for the underground plant and high head of 2,930 feet. Taipower is now constructing a 90-MW plant on the Tanshui River and a 360-MW plant on the Tachia River. These plants are scheduled to go into operation in 1963 and 1966 in that order. An outstanding feature of the Tachia development is the 780-foot concrete arch dam—the last important dam designed by the late Andre Coyne of France. The project is a unit in a six-plant scheme that will have a combined capacity of 1,330 MW (Water Power, Nov. 1959, p. 425).

India

India is making progress in water-resource development, but much more is needed. The recent agreement with Pakistan on the division of Indus River water removes an obstruction that was retarding water-resource developments in both countries. The Indus in the reach concerned is about the size of the Columbia River at Bonneville Dam. The Indus irrigates nearly 30 million acres and about one-third of its flow goes to the sea unused (65 million acre-feet) (Eng. News-Rec., Sept. 22, 1960, p. 262). The Kundah hydroelectric project in Madras State (Dharmalingam, 1959), the Periyar project also in Madras State (Rajan, 1959), and the Rihand project in Uttar Pradesh (O'Connor, 1962) are examples of current multiple-purpose projects. The Rihand reservoir on the Rihand River (tributary by way of Sone River to the Ganges), will have a capacity of 8,600,000 acre-feet and an area of 180 square miles. The initial capacity of the powerplant will be 250 MW in five units, and a sixth unit is planned (Water Power, Mar. 1962, p. 89). Wainganga Reservoir, now under construction, will store 33 million acre-feet of water.

Iran

The Karadj Dam, Karadj River, was almost complete by January 1, 1962 (Bowman, 1961). The dam is 590 feet high and will have 110 MW installed ultimately. Two 40-MW units are presently producing power. The World Bank has approved a loan equivalent to $42 million for the construction of a multiple-purpose project on the Dez River. The powerplant will have two 65-MW generating units (Water Power, Apr. 1960, p. 127). Manjil Dam on the Sefid Roud is also complete and two 18-MW units are in operation (Water Power, Aug. 1962, p. 295).

Iraq

Derbendi Khan Dam on Diyola River was recently completed. The project is principally for providing irrigation water and it was not learned whether any power installations have been included.

Israel

There probably are no waterpower plants in Israel. The Dead Sea on the boundary between Israel and Jordan is 1,286 feet below sea level and only 50 miles from the Mediterranean; thus, a good opportunity exists for development of power.

Japan

The theoretical potential waterpower of Japan has been computed at 77,300 MW. The installable capacity estimate is 35,400 MW, of which 12,700 MW have been installed. Projected production of 60.7×10^9 kwhr from the undeveloped sites indicates an undeveloped potential of 8,671 MW at 80 percent efficiency (World Power Conf., 1962, reprint 151 I.2/20). The estimate of 18,750 MW for mean flow in table 13 is 24 percent of gross theoretical and 50 percent of estimated installable power.

Recent trends in Japanese waterpower development are presented in descriptions of three recent Japanese plants: Kurobegawa No. 4 plant on the Kurobe River; Miboro plant on the Sho River in the Hida Mountains; and the Okatadami plant on the upper Tadami River (Kito, 1961).

Kurobegawa No. 4, partly in operation, is to have an installed capacity of 285 MW. The dam is a cupola-arch 617 feet high, the largest of this type in Japan. The reservoir will store 162,000 acre-feet of water. Usable storage capacity is about 121,000 acre-feet. The power station is totally underground and contains three vertical-shaft single-runner six-nozzle Pelton wheels.

The Miboro plant, just coming into service, has an installed capacity of 215 MW. Active storage in the reservoir is 268,000 acre-feet. Installations aggregating 300 MW at seven downstream plants will benefit from the improved regulation afforded by Miboro. Miboro is the first rockfill structure in Japan and is one of the largest dams of its kind in the world (430 feet high and 1,328 feet long). The rockfill dam was chosen because of the availability of an excellent quality granite fill material and because of a major fault 100 feet wide running parallel to the river at the damsite. The powerhouse is 295 feet below ground and houses two 117-MW generating sets of vertical Francis turbines operating under a head of 590 feet.

The Okatadami is a gravity-type dam 515 feet high and 1,558 feet long. The reservoir provides 370,000 acre-feet of storage. The 360-MW plant was placed underground to avoid difficulties due to snow which sometimes reaches depths of 26 feet. Three 120-MW vertical Francis generating sets are installed and a surge chamber is provided.

The Omorigawa pumped-storage plant, completed in 1959 on the Yoshino River, contains the first reversible pump turbine sets used in Japan. The capacity as a generator is 12.2 MW, and it requires 14.3 MW as a pump. The project is on the island of Shikoku, which receives about 86 inches of precipitation annually. The island is driest from November to February and the need for reusing the water is most pronounced at that time (Shiwa, 1960).

The Tagokura plant on the Tadami River is Japan's largest hydroelectric station. When fully developed, the plants capacity will be over 2,000 MW and it will be the largest waterpower source in the country (Water Power, Mar. 1963, p. 110).

Korea

The estimates shown for Korea in table 13 are for North and South Korea and are prewar amounts.

United Nations statistics show the Republic of Korea as having 431 MW of total electric generating installations, and 143 MW of hydroelectric installations in 1960 (U. N. Stat. Yearbook, 1961, p. 294). The World Power Conference (1962) shows it as 143 MW in 1959. It is not known how well these States have maintained the plants left by Japan, but a North Korean project partly completed on the Kange River in 1942 has been carried to completion. Through heads of 1,310, 522, and 342 feet discharges of 470, 706, and 70 cfs develop 141 MW, 56.4 MW, and 33.6 MW, respectively. When completely harnessed the Kange River will supply the major part of North Korean power (Water Power, Mar. 1961, p. 124).

Laos

The United Nations Economic Commission for Asia and the Far East is conducting investigations that may lead to better use of the Mekong River. One damsite is at Pa Mong just upstream from Vientiane, Laos (Eng. News-Rec., May 24, 1962, p. 96). Jones and Young (1954) and Young (1955) included Laos with French IndoChina in their reports. Studies to divide the estimate by countries have not been made and the total waterpower is included with Vietnam.

Malaya

An important power development 100 miles north of the capital, Kuala Lumpur, will use the water from four rivers on the Cameron Highlands Plateau. It will include a dam 120 feet high, 15 miles of tunnel, and two power stations. The larger station at Jor will be underground and house four 25-MW sets under a gross head of 1,880 feet. A smaller station at Habu will house two 2.75-MW sets (Water Power, Jan. 1962, p. 2).

Nepal

Two projects have been approved and at least one is under construction on rivers common to Nepal and India. One is on the Gandak River on the Indo-Nepal border, the other on the Kosi River. The latter river rises in Tibet, flows through Nepal and Bihar. The Gandak project will have a powerplant with 10,000-kw capacity, and the Kosi River project (definitely known to be under construction) includes a powerhouse with an initial capacity of 13,200 kw. The United Nations is helping with a survey of the Karnali River basin (Water Power, Jan. 1960, p. 4; Eng. News-Rec., Feb. 14, 1957, p. 66, Feb. 8, 1962, p. 28).

Pakistan

Pakistan is making extensive investigations and has elaborate plans for water-resource development. In 1958 a West Pakistan water and power development authority was established to oversee the development of water and power on a unified and multiple-purpose basis, including water supply, drainage, power, flood control, reclamation, navigation, irrigation, and public health (Water Power, May 1960, p. 168). The Warsak hydroelectric project, recently completed by Canadian engineers and the Pakistan government under the 1950 Colombo plan is an important development. The dam and powerplant, with four 40-MW units installed, are located on the Kabul River between its junction with the Indus River and the Afghanistan border. Structures are designed to withstand a flood of 540,000 cfs—frequency of occurrence of about 1 in 10,000 years (Martin and Tech, 1960). Mangla Dam now under construction on the Jhelum River in the Indus Basin is essential to the water-use settlement between India and Pakistan (Eng. News-Rec., May 10, 1962, p. 64). The dam will be 375 feet high and have a volume of 76 million cubic yards. The reservoir will store 45 million acre-feet of water and provision will be made for a future heightening of 40 feet. The powerplant will contain three 100-MW generators, two of which are scheduled to be installed by 1968 (Water Power, Mar. 1962, p. 87).

Philippines

The installed capacity shown for the Phillippines in table 13 is from World Power Conference (1962, reprint 192 I.2/26). The article also indicates that 2,270 MW are installable.

Hydroelectric installations have approximately quadrupled in the Philippine Islands since 1955, but demand still exceeds supply. Studies indicate that power installations must be increased by about 12 percent per year over the next 10 years if Manila on Luzon Island is to have an adequate power supply. The World Bank has approved a loan to develop 206 MW on Angat River about 25 miles north of Manila. There will be a rockfill dam 410 feet high and a 460,000 acre-foot reservoir. A 4,600-foot pressure tunnel will carry water to a 200-MW plant consisting of four 50-MW units and an additional 6-MW plant (Water Power, Jan. 1962, p. 2).

The 100-MW Binga project on the Agno River, Luzon Island, is the largest developed project in the Philippines. It was preceded by the second largest, the Ambuklao Reservoir and 75-MW plant upstream on the same river. Luzon is in the South Pacific typhoon zone and holds the world's record for rainfall intensity—46 inches fell in 24 hours and 88 inches in 4 days (Enstrom, 1961). Nearly all rainfall occurs between May and November. Large reservoirs and spacious spillway outlets are required.

According to a recent study by the International Atomic Agency, Vienna, a nuclear power station consisting of two 100-MW units planned for the Manila area in 1967 or 1968 may be competitive over its lifetime with an oil-fired station (Water Power, Dec. 1961, p. 460).

Syria

Recent and planned water resource developments in Syria will reduce the effects of catastrophic droughts and increase hydroelectric energy generation. Two rockfill dams, Rastane and Mehardeh, on the Orontes River were put in service in 1961 for irrigation, flood control, and hydroelectric generation. A powerplant at Sedjar has an installed capacity of 7.5 MW. Water is supplied to the plant through a pressure tunnel from the Rastane Reservoir (Water Power, Oct. 1962, p. 419). A multiple-purpose project on the Euphrates is being planned for irrigation, flood control, and power (Water Power, Apr. 1963, p. 135).

Thailand

The installed capacity shown for Thailand in table 13 is the same as the 1954 figure and may duplicate some of the capacity given for Malaya. The potentials shown are estimated to be about four-fifths of 1954 amounts for Siam and Malay States.

In new construction and rehabilitation work, Thailand is setting the pace in southeast Asia (Bowman, 1962a; Robinson, 1960). The Bumiphol (Yanhee) multiple-purpose project on the Mae Ping some 250 miles northwest of Bangkok is the largest ever undertaken in the area. Ultimate capacity of the plant at the Bhumiphol Dam is 560 MW. Two 70-MW units are to be put in operation in 1963. An irrigation dam near Chainat was placed in operation at the end of February 1957 (Xujati, 1957). Studies are underway and plans are taking shape for even greater projects on the Mekong River.

Tibet

The most recent and most important waterpower installation in Tibet is the 7.5 MW Lhasa plant using equipment produced in China (Water Power, July 1960, p. 254).

Turkey

A study by the United Nations Economic Commission for Europe (1955) determined gross hydroelectric power to be 61,248 MW (207 kw per sq mi). Further analysis by the Commission determined that 27.3 percent of this (56.5 kw per sq. mi.) can be considered technically feasible. This is the source of the mean-flow estimate shown in table 13. The ordinary minimum flow estimate is a proportional increase of the amount reported by Jones and Young (1954). According to the Commission, 17 percent of gross potential is economic in Turkey. A report for the World Power Conference (1962, preprint 135 I.2/15) is in general agreement with the United Nations study.

Development of waterpower resources is now centering on the Euphrates and Tigris Rivers and plans are for 11 major dams. The key structure, Keban Dam, is now under construction. The energy supply in the country reportedly is growing faster than the demand. There is immediate need for a flood-control dam in the headwaters of the Euphrates (Rouve, 1961; Bowman, 1957).

Vietnam Republic

The developed and potential power estimates shown for Vietnam Republic in table 13 are those formerly reported for French IndoChina and, because studies for properly dividing them have not been made, include Laos.

The Mekong River is common to Vietnam, Cambodia, Laos, and Thailand. Large power developments on the Mekong may be feasible because of the iron ore, gypsum, bauxite, tin, and softwood resources of the area.

AUSTRALIA AND OCEANIA

Islands for which potential power estimates have been made and those in which waterpower developments are known are:

Indonesian Islands—Borneo, Java, Sumatra
Malanesian Islands—New Caledonia and New Guinea
Polynesian Islands—New Zealand and Samoa

The Philippine Islands, which were included in Oceania by Jones and Young (1954), are now included with Asian countries.

The principal recent activity in waterpower development has been in Australia and New Zealand.

Australia

The economic potential waterpower has been estimated to be 2,600 MW (World Power Conf., 1962, reprint 190 I.2/25).

The only region of Australia that is high enouth to regularly receive winter snowfall is the highlands in New South Wales and Victoria. These two States, and to a lesser extent Queensland, contain most of the developed waterpower and possibilities for future development on the mainland. Waterpower development is possible on the Queensland plateau (2,000 to 3,000 feet in altitude with some 4,000-foot peaks) if storage is provided. About 3,000 MW are planned for the next 25 years (Commonwealth of Australia, 1959, p. 213).

Table 14.—Installed capacity of hydroelectric plants, 10-year growth ratio, hydroelectric as percent of total generating installations, and estimated gross theoretical power of developed and potential sites of Australia and Oceania

[U, unknown or not found]

	Installed capacity[1] (approx, in MW)	10-year growth ratio (normal = 2 Jan. 1, 1955 = 1)	Percent of total (approx)	Estimated gross theoretical potential (MW)	
				Q95	Arithmetic mean
Australia	2,000	4.84	25	750	28,500
Indonesia	200	1.66	U	9,000	77,000
N. Caledonia	100	10.8	75	U	U
N. Guinea[2]	5.6	1.08	57	4,000	22,500
New Zealand	1,550	1.91	80	3,750	8,250
Papua	3	U	55	1,100	7,500
Samoa	1.3	4.36	55	U	U
Timor	.2	U	U	U	U
Total	3,860	----	--	18,600	143,750
Weighted avg	------	2.60	40	------	-------

[1]As of Dec. 31, 1962.
[2]All developed power is in Australian N. Guinea.

The Tulley Falls scheme completed in 1957 in north Queensland is an example of what might be termed a small development in many places. Drainage area above the falls is about 100 square miles and rainfall there averages 90 to 100 inches annually. The Koombooloomba Reservoir, 7 miles upstream (152,000 acre-feet), regulates the flow of the stream (500 cfs average) to not less than 268 cfs. In the Tulley Falls section the Tulley River falls approximately 1,500 feet in 2 miles. Four 18-MW Pelton-type wheels are installed in the powerhouse at the lower end of this section. The first steel-tower transmission line in Queensland carries the power to Innisfail and Cairns. Lines also radiate from the station to other nearby centers in north Queensland (Water Power, Mar. 1958, p. 113).

A 55-MW plant under 405 feet of head, a 5.4-MW plant under 230 feet of head, and a peaking plant (Barron Falls) of 60 MW under 920 feet of head are planned additions. The latter is scheduled for 1967. An earth and rockfill dam on Flaggy Creek, a tributary of the Barron, will provide storage so that the plant can operate at 25 percent load factor (Commonwealth of Australia, 1959). The Barron Falls station is now under construction near Kuranda (Civil Eng., June 3, 1960, p. 40).

In New South Wales the following plants were in operation in 1959: Hume (50 MW); Burrinjuck (20MW); Oakey River (5.25 MW); Nymboida River (4.65 MW); Bemboka River (3.95 MW); Wilson Creek (0.15 MW) (Commonwealth of Australia 1959). A 50-MW plant was under construction at Warragamba Dam on the Warragamba River as was a small station (6 MW) at the foot of Keepit Dam on the Namoi River. The latter will be remote controlled from New Castle 140 miles away. The turbine is a vertical-shaft Francis type and will normally be run through the morning and evening periods (Water Power, Aug. 1958, p. 284).

The Warragamba Dam on Warragamba River near Sidney, officially opened in October 1960, is one of the largest dams in the world built primarily for metropolitan water supply. From a base 340 feet long, the concrete-gravity dam rises to a height of 450 feet. A 55-MW powerplant with remote control by radio is included (Water Power, Dec. 1960, p. 456). A world record in rock-tunnel driving (525 feet in 7 working days) was claimed by the breakthrough of the 9-mile Kooma-Tumut Tunnel on the Snowy Mountain project. The Tumut I power station on the Snowy Mountains was put in operation in May 1959 with a capacity of 160 MW. The power is distributed over New South Wales and Victoria systems. Water for this plant is stored in Tumut Pond, Tumut River. It passes through a pressure tunnel and drops nearly 1,000 feet through steel-lined pressure shafts to the power station 1,200 feet below the surface (Water Power, Aug. 1959, p. 285). The Tumut I station will have a capacity of 320 MW and will operate with a capacity factor of 32 percent. It is scheduled for completion in 1963 (Jaggar, 1960).

The Snowy Mountain hydroelectric development is divided geographically into the Snowy-Tumut and the Snowy-Murray areas. The Eucumbene Reservoir serves the Tumut I and II power stations. The next development is the Murray I. This will be the first station in the Murray section and will be the largest station in the system. Contracts have been let for eight 95-MW Francis turbines. These, it is believed, are the largest Francis machines in the world operating under such a great head (1,719 feet) (Water Power, Dec. 1961, p. 499).

In Victoria 87.6 MW was installed in two stations in 1959, and the 96-MW McKay Creek hydroelectric station on the slopes of Mount McKay in the Australian Alps began operating in May 1960. The sixth and last 16-MW unit is now in operation and brings the Kiewa development to a total capacity of 184 MW. The turbines work under a gross head of 1,730 feet in an underground station. The water is used three times—on McKay Creek (96 MW), at Clover station on East Kiewa River (26 MW), and at West Kiewa River (62 MW) (Water Power, June 1962, p. 213).

The Eildon Reservoir, a recently completed project on the Goulburn River, extends irrigation and hydroelectric power in central Victoria. The old Eildon Reservoir (306,000 acre-feet) was completed and two small 8-MW generators were placed in operation in 1954. The Goulburn is the largest river in the State of Victoria and the new Eildon Dam, about 260 feet high and some 3,300 feet long, is one of the world's large rockfill dams. The reservoir has a capacity of 2,750,000 acre-feet. Two additional turbogenerators presumably have been installed by this time, each having a capacity of 60 MW and designed for operation at heads between 77 and 150 feet. Interchangeable runners are provided to make the turbines suitable for operation at heads ranging from 150 to 235 feet (Water Power, Apr. 1957, p. 123).

In contrast to the mainland, where coal-fired plants predominate, Tasmania relies principally on waterpower and will continue to do so. The installable capacity of plants on the island is 617 MW, and 917 MW is planned by 1966. Principal power development to date has been on the tributaries to the Derwent River on the central plateau. The plateau contains many lakes and other favorable storage sites, and dam construction has been carried to a point where the plateau runoff is almost completely controlled. The Tungatinah power station on the Nive River is the most impressive of existing developments. The 125 MW capacity of the station is from five 25-MW units under a head of 1,005 feet. Regulation having been achieved, there remains the problem of developing the head. In general, plants in the plateau area have high heads with small discharges and those farther down the Derwent have lower heads and correspondingly greater discharges. A low-head development at the mouth of the Nive River will add 48 MW by 1962. The most impressive development now underway is at Great Lake where the Poatina underground power station, under a vertical head of 2,720 feet, will have installations totaling 300 MW (Commonwealth of Australia, 1959). The fifth 62-MW Pelton turbine for the Poatina station has been installed. This is the first underground power station in Tasmania and the highest head yet developed in the Commonwealth (Water Power, Oct. 1960, p. 374). The scheme also includes pumped storage from Arthurs Lakes to Great Lake (Water Power, Nov. 1962, p. 424). The Catagunya Dam on Derwent River in Tasmania is being completed and equipped with two Francis turbines, each driving 24-MW alternators under a head of 145 feet. An estimated saving of about 20 percent of the cost of a gravity dam is being realized by the use of prestressed concrete (Wilkins and Fidler, 1960).

In the external territory of Papua and New Guinea exists an immense potential for hydroelectric development, very little of which has been developed by public means (3.13 MW with an additional 5.5 MW being produced in a private undertaking). Present installations range upward from 5-kw units. Plans for the future include more small plants, but there are possibilities for major hydroelectric developments as follows: Rouna Falls (near Port Moresby); Upper Snake and Busu-Erap-Leron (near Lae); Upper Ramu (near Markham-Ramu divide 80 miles from Lae); and Hathor Gorge (on Purari River) with estimated average power potentials of 100 MW, 150 MW, 2,000 MW, 250 MW, and 3,000 MW respectively (Commonwealth of Australia, 1959).

The Australians are studying a tidal-power resource off the Kimberly coast in western Australia. Tides there are as much as 40 feet, and the steep rugged coastline is indented by many estuaries with small outlets. The Australian Government is observing progress at the Rance tidal development near St. Malo, France, and production design engineer J. G. Lewis is planning 45 tidal projects. Australia is also investigating direct-current transmission to possible use centers located at long distances from the coast (Water Power, Jan. 1963, p. 3).

Indonesia: Java, Sumatra, Borneo, Celebes

The Republic of Indonesia lies astride the equator from about lat 5° N. to 10° So. and between long 95° and 140° E. In all, more than 3,000 islands covering a land area of about 575,890 square miles are included in the Republic. The principal islands are Borneo, Celebes, Java, and Sumatra of the Greater Sunda Islands; Bali, Flores, Lombok, Sumba, Sumbawa, and Timor, in the Lesser Sunda Islands. Indonesia also claims the west half of the island of New Guinea. Borneo, with its 286,969 square miles, is the third largest island in the world. About one-fourth of Borneo (its northern part) constitutes the British protectorate of Brunei and the British colonies of North Borneo and Sarawak. Borneo's potential waterpower is arbitrarily assumed to be one-half of the amounts given by Young (1955) for Borneo, New Guinea, and Papua. The island of Timor is also divided about equally between Indonesia and Portuguese Timor.

Rainfall is heavy throughout the islands, ranging from 80 to 144 inches annually. A November to March monsoon brings rain from the Indian Ocean, and a June to October monsoon brings rain from the southeast. The islands are principally of volcanic origin and are mountainous. In the Indonesian part of Borneo, Mount Jaja rises to 7,474 feet, Mount Kajan to 9,800 feet, and Mount Obong to 7,545 feet. The mountain range connecting these peaks divides Borneo approximately in half from the southwest to the northeast. Mount Kinabalu, at the northernmost tip of the island, is 13,455 feet high. Other prominent mountains and their altitudes are: Mount Rantemario, in the Celebes, 11,286 feet; Mount Semeru in Java, 12,060 feet; Mount Kerintji in Sumatra, 12,484 feet; and Mount Ramelau in Timor, 9,678 feet.

New potential power estimates for these islands would surely indicate larger amounts than those given here. Assuming the average altitude of the islands to be 2,000 feet and the average runoff 80 inches, the gross theoretical waterpower should be 1,000 kw per sq. mi. or a total of 575,890 MW at average discharge for the entire Republic. Some 30 to 40 percent of this might be at technically feasible sites, increasing the estimated 77,000 MW in table 14 to perhaps 200,000 MW. This is 347 kw per sq. mi, which compares favorably with the resources of countries like Switzerland, richly endowed with hydroelectric power.

New Caledonia

An old project built on the Yate River in 1926 has recently been replaced by a new dam and 80-MW powerplant designed by the late Andre Coyne and Jean Bellier. The dam is of combination arch and buttress with a gravity section and overflow spillway (Water Power, Jan. 1962, p. 43).

New Caledonia has an average annual rainfall of more than 160 inches; its streams are short and flashy; nevertheless, considerable opportunity exists for development of waterpower.

New Zealand

Of New Zealand's two main islands, South Island has the greater waterpower potential. A high mountain range parallel to the northwest coast of the island intercepts a large amount of precipitation, which is held first as snow and then in lakes in the headwaters of rivers that drain eastward into the Pacific Ocean. Power development on South Island is made economically feasible by direct-current transmission across Cook Strait to Wellington on North Island. This direct-current link has a capacity of 600 MW over a 500-kv line (Water Power, Dec. 1961, p. 461).

The principal effort has been centered around the Waitaki River on South Island, where 11 power developments are contemplated. Regulating storage is being provided in three Lakes, Tekapo, Pukaki, and Ohau, and three reservoirs, Benmore, Waitangi, and Waitaki. When completed, Benmore will probably be the largest station in Oceania. The powerplant will have an installed capacity of 540 MW, the earth dam will be 360 feet high with 17 million cubic yards of fill, and the reservoir will store 1,650,000 acre-feet of water, making it the largest manmade lake in New Zealand (Water Power, Dec. 1957, p. 469).

The Roxburgh project on the Clutha River near the southeast corner of South Island is the first important development on this river. The river is fed principally by snowfields and glaciers and is partly regulated by large natural lakes on three of its upstream branches. At the Roxburgh site average discharge is 17,650 cfs. A flood of 117,000 cfs was recorded in 1878, and discharge fell below 7,500 cfs on five occasions during a 17-year period (Water Power, Feb. 1957, p. 44). The dam is in the lower end of Roxburgh Gorge near the town of Roxburgh. Ultimately there will be eight generating sets, the first four being rated at 40 MW each. The normal operating head is 150 feet.

North Island has only one large lake, Lake Taubo. This lake has a regulating effect on the Waikato River. The fifth development on Waikato River is underway at Atiamuri Dam, and connected 84-MW powerhouse (Water Power, Oct. 1959, p. 393). To prevent damage to scenery by a 90-MW power development on the Waikato at Aratiatia, construction is being carried out from each end of the rapids without building roads alongside them (Water Power, Oct. 1960, p. 374).

EUROPE

Europe leads all continents in the actual use of hydroelectricity, and many European countries strive for operating schedules that save coal. The effectiveness of this coal-saving plan is illustrated in the following tabulation (data from UNIPEDE,[1] Oct. 1961). Note especially, Switzerland, Italy, and France. Hydroelectric capacity increased 88 percent in Europe between January 1, 1955 and December 31, 1962, and about 40 percent of the electric energy used in European countries is produced by waterpower.

[1]Union Internationole des Producteurs et Distributeurs D'Energie Electrique, Paris.

Status of hydroelectric and steam generation for selected countries in Europe

	Production 1960 (kwhr × 10^6)	Hydroelectric generation (percent)	Hydroelectric installations (percent)
Switzerland----------	20,700	99.2	96
Italy ----------------	54,200	83.5	72
Austria -------------	15,900	74.4	70
France--------------	72,200	55.9	47
Germany ------------	107,200	10.3	12
Belgium-------------	14,100	1.3	1
Total ------	284,300	----	--
Weighted avg	-------	45.4	45

Table 15.—Installed capacity of hydroelectric plants, 10-year growth ratio, hydroelectric as percent of total generating installations, and estimated gross theoretical power of developed and potential sites of Europe

[U, unknown or not found]

	Installed capacity[1] (approx, in MW)	10-year growth ratio (normal = 2 Jan. 1, 1955 = 1)	Percent of total (approx)	Estimated gross theoretical potential (MW)	
				Q95	Arithmetic mean
Albania -------------	[2]10	1.90	U	200	1,500
Austria -------------	3,600	2.56	75	3,000	7,000
Belgium-------------	[3,4]54	1.18	1	56	225
Bulgaria ------------	480	13.5	50	225	750
Czechoslovakia ------	1,080	2.06	17	525	1,800
Denmark ------------	10	U	0.5	22	75
Faeroe Islands-------	8	2.38	73	U	U
Finland -------------	1,730	2.40	53	750	2,000
France---------------	10,900	1.57	47	4,000	12,000
Germany (Federal Republic)----------	[5]3,500	1.36	12	[5]1,640	[5]3,750
Germany (East) ------	130	U	U	-----	
Greece---------------	250	2.56	35	263	2,250
Hungary-------------	[6]19	2.94	2	100	330
Iceland--------------	110	1.57	75	525	2,250
Ireland--------------	219	1.14	30	375	1,125
Italy ----------------	[3]12,700	2.07	72	4,500	15,000
Luxembourg ---------	16	16.0	U	U	U
Netherlands ---------	0	0	0	19	75
Norway -------------	7,600	2.13	98	7,500	21,000
Poland --------------	260	1.14	1	750	1,200
Portugal ------------	1,400	2.58	80	700	5,800
Romania ------------	230	2.90	20	1,500	3,000
Spain ---------------	4,850	1.80	70	2,625	12,000
Sweden--------------	8,300	1.92	78	5,000	[3]22,500
Switzerland----------	6,400	2.08	96	2,250	7,000
U.S.S.R -------------	[7]19,000	4.23	20	15,000	75,000
United Kingdom ------	1,350	1.86	3	562	1,875
Yugoslavia ----------	1,600	3.11	60	2,400	10,000
Total --------	85,806	----	--	54.687	209,505
Weighted avg -	------	2.20	40	------	-------

[1]As of Dec. 31, 1962.
[2]Estimated from United Nations production reports.
[3]From World Power Conf. (1962).
[4]Apparently includes about 6 MW in water wheels not generating electricity.
[5]Includes Saar.
[6]From UNIPEDE (1961).
[7]Includes Asian U.S.S.R.

Austria

The United Nations Economic Commission for Europe (1961) estimated Austria's gross theoretical waterpower potential at average discharge to be 17,409 MW with 100 percent utilization. The mean-flow estimate indicates that 64 percent of this is technically developable (World Power Conf., 1962, reprint 5 I.2/3), and an estimated 26 percent of gross potential is economically feasible in Austria (U. N. Econ. Comm. for Europe, 1955). Another estimate is that 11,200 MW are installable and could produce 43 x 10^9 kwhr (World Power Conf., 1962, reprint 51.2/3). This equals 4,900 MW at 100 percent efficiency, 6,140 MW at 80 percent efficiency, and 7,000 MW at 70 percent efficiency.

The highest head development in the world, the Kolbnitz power station in the Reisseck-Kreuzeck scheme, has been achieved in Austria since 1955. In addition to the head of 5,810 feet between the Hochalpensee Reservoir and the Kolbnitz Tailrace, the scheme includes annual storage, run-of-river plants, and pumped storage. The development is on the Moll, a Drau tributary (Water Power, May 1961, p. 171).

The Drau River flows through several countries, and waterpower development has been complicated for that reason and for the further circumstance that the international boundaries in the area have been changed several times during this century. The first plant on the Drau was the Faal plant built in 1918. At the close of World II several Drau plants fell to Yugoslavia, and an agreement exists that requires Austria to supply water for the downstream plants. A plan now being executed will almost completely develop the Drau by means of small plants—Feisteritz (41.7 MW), Hollenburg (68 MW), Ferlach (24.5 MW), Dullach (27.5 MW), Rottenstein (25 MW), and Annabrucke (23.8 MW).

A project is now under construction on the Isel, a Drau tributary in Eastern Tyrol, that will have a head of 2,532 feet and a 150-MW powerplant. The dam will create a reservoir of 81,070 acre-feet. A 6.2-mile low-pressure tunnel will carry the water to a surge tank and an underground powerhouse including a tailrace partly in tunnel. Four steel penstocks will take the water to four Pelton units of 47 MW (Konigshofer, 1961).

The Ybbs-Persenbeug plant on the Danube was completed in 1959 with an installed capacity of 1,140 MW and is one of the largest hydroelectric schemes in Europe. The first of the present six generating sets was installed in 1957. Other recent developments in Austria have been accomplished on the Salzach, Zemme, and Gerlos Rivers (Konigshofer, 1958).

Comparison of UNIPEDE and World Power Conference statistics indicates that Austria has the equivalent of 500 MW in water wheels that do not produce electricity.

Bulgaria

A six-station development on the Vacha River is scheduled to add 436 MW to the Bulgarian system by the end of 1965 (Water Power, June 1962, p. 212). The principal structure in the project is Dospat Dam, which will be one of the country's largest and will form a reservoir of 360,800 acre-feet of water. The Studen Kladnets Dam and powerplant on the Arda River were commissioned in 1958 (Water Power, Oct. 1958, p. 365).

A recent study indicates that Bulgaria has an average yearly rainfall of about 26 inches. The country has a problem of harmonizing hydroelectric developments with irrigation and domestic requirements. This has led to a general pattern of power development in headwaters areas and irrigation in the lower reaches. The Arda and Vacha developments in the Rhodope Mountains are of this type (Baydanoff, 1955).

Czechoslovakia

The installed capacity shown for Czechoslovakia in table 15 is from United Nations statistics for 1960 (U. N. Stat. Yearbook, 1961, p. 295) with an estimate of 1961 and 1962 additions.

The United Nations Economic Commission for Europe (1961) estimate the gross theoretical waterpower potential at average discharge to be 4,486 MW with 100 percent utilization. The estimate in table 15 indicates that 41 percent of this is technically developable. According to the Commission, 32 percent of the gross potential is economically feasible in Czechoslovakia. Waterpower plants are used almost exclusively for peaking purposes and are, therefore, built in conjunction with dams. An example of this is the 150-MW Slapy plant on the Vltava River, completed since 1955. Its powerplant is made up of three 50-MW Kaplan sets suitable for heads of 79 to 184 feet. The Vltava River now has seven dams with connecting powerplants, and with construction of three more dams the river will be completely developed above Prague (Nechleba, 1960).

Finland

Finland has approximately doubled installed capacity in hydroelectric plants since January 1, 1955. Developments in Finland are mostly lowhead, but natural lakes and basins capable of fairly large storage are available.

Waterpower continues to be the principal source of energy in Finland. A recent estimate is that Finland has a potential waterpower of 30 billion kwhr (3,425 MW at 100 percent utilization) and that at least half of that amount is technically available for harnessing (Veijola, 1956). About three-fourths of the waterpower resources are in north Finland—the Oulujoki and Kemijoki Rivers being among the most important. The Kemijoki is the largest of these. Some 30 powerplants and 9 artificial reservoirs are planned for the Kemijoki drainage. The largest reservoir is to have a surface area of 193 square miles and a capacity of 1,621,000 acre-feet.

Representative of powerplants put in operation recently in the Kemijoki Basin are: Jumisko plant, with 30 MW operating under a head of 315 feet and a remote-controlled powerhouse located 164 feet below ground; Isohaara at the mouth of the river, with two 23-MW units operating under a head of 40 feet; and Petajaskoski, the largest station on the river, with 125 MW and a head of 66 feet (Veijola, 1956).

Another important river, the Oulu in north Finland, is now approaching full development. Of its eventual 530-MW capacity, 430 MW are installed (Water Power, June 1961, p. 227). Developments are much the same as on the Kemijoki River with the exception that more natural lakes are available for storage. Pyhakoski, installed capacity 120 MW and mean head 106 feet, is the largest station on the river. Merikoski is the smallest at 36 MW with a head of 36 feet. The cheapest power was obtained at Nuojua, where an 80-MW plant operating under an average head of 72 feet was constructed at a cost of about $240 per kw installed (Water Power, Aug. 1961, p. 321).

France

The United Nations Economic Commission for Europe (1961) estimated the gross theoretical water-power potential at average discharge to be 29,110 MW with 100 percent utilization. The estimate in table 15 indicates that 41 percent of this is technically developable. According to the Commission, 24 percent of the gross potential is economic in France.

Tignes Dam on the Isere River is the highest dam in France, rising 593 feet by gravity arch above its foundations. Power is produced in a plant at the base of the dam (Brevieres) and in a plant at Malgovert. Heads are 755 and 2,400 feet, and plant capacities are 180 MW and 320 MW in that order. Freezing and thawing were problems at Tignes, and air-entrained concrete was used throughout (Portland Cement Assoc., 1962).

Perhaps the most spectacular development in France in recent years is Roseland in the Isere River basin. The water for that project is collected by automatic intakes from many mountain streams and stored in Roseland Reservoir on the Doron de Roseland (Water Power, Jan., 1961, p. 5). Conduits and tunnels carry the water to a surge chamber high above the Isere River at La Bathie, where it falls 3,940 feet to a 500-MW powerhouse. Another bold development in the Isere River basin is at Monteynard on the Drac. The project consists of a dam and 195,000 acre-foot reservoir (122,000 acre-feet usable), with a 320-MW powerplant operating under an average head of 417 feet. The dam is concrete arch with a twin ski jump spillway. There are four units of 80 MW each driven by Francis turbines. The powerhouse is inside the dam as a protection against slides (Bowman, 1962c).

The continuing development of the Drac, a turbulent mountain river running through deep gorges, underlines a trend toward development of steep-gradient streams by dams rather than by conduits. The Drac, a tributary to the Isere upstream from Grenoble, falls more than 50 feet per mile throughout its length and carries large quantities of debris. When completed, about 1,890 feet of gross head will be developed in eight projects—five create head by dam entirely and three combine dam and conduit (La Houille Blanche, Aug.-Sept. 1961, p. 496), Bowman, 1962c).

About 40 percent of the potential power of the lower Rhone River has been developed by the Jenissait, Seyssel, Donzer-Mondragon, and Montelimar plants. Five additional developments will increase the peak-load power of the river by 250 MW for a 4-hour period. The development of the Rhone is multiple-purpose in all respects. It will add to the importance of the river as a navigational artery, furnish much needed water for irrigation, and also enhance the domestic water supply of many cities in the valley (Water Power, June 1960, p. 215).

Argentat is the final stage in the exploitation of the upper Dordogne. Upstream developments are: Bort-les-Orgues, Val Beneyte Roche-le-Peyroux, L'Aigle, and Marcillac. All these projects include storage of water and diversion to increase the drainage areas (Water Power, Oct. 1957, p. 365).

The Montpezat scheme also deserves mention. It includes diversion of water from the Loire River basin across a divide in the Massif Central to the Rhone River basin, and an underground power station fed by pressure tunnels from three reservoirs in the Loire River basin. Plant capacity is 116 MW and 776 cfs is used under a head of 2,100 feet (Water Power, June 1956, p. 226).

The world's first major tidal-power project is now under construction on the Rance estuary near Saint Malo. Electricite de France played a vital part in the study of tidal power and, in preparation for the Rance development, experimented with and improved the horizontal Kaplan-type turbine-alternator unit. The tubular turbine has evolved over a long period of time. In 1919 and 1924, L. F. Harza secured patents, and Arno Fischer in Germany and Escher Wyss in Switzerland continued development of the horizontal runner-ring-type turbine alternator (Water Power, Oct. 1957, p. 365).

Tides in the Rance estuary are among the most pronounced in the world. Two high-water and two low-water tides occur in 24 hours and 50 minutes, and the difference in level between consecutive high and low tides may be as much as 44 feet. Preparatory work on the project began in 1960 and construction work in

1961. Completion is scheduled in 6 years. Installations will total 240 MW in 24 bulb sets that are operable pumps or turbines in either direction. The design of these sets is based on actual tests of bulb sets on the Truyere at Cambriac, the Dordogne at Argentat, the Isere at Beaumont-Monteux, and at a tidal installation at an used lock on the Rance at Saint Malo. Production will be 544,000 MWhr per year—equal to a plant factor of 26 percent for a conventional water-power plant (La Houille Blanche, Mar.-Apr. 1962, p. 129).

Germany (Federal Republic)

The first run-of-river plant in what is now the German Federal Republic was a 1,700-hp (horsepower) plant built on the Neckar in 1891. Twenty-three additional plants had been put into service by 1921, when total installed capacity was about 48 MW. Planning and multiple-purpose development began with the Reich in 1921. By the end of 1958, 85 plants with a total capacity of 434.53 MW were installed. At that time there were 64 plants in the course of construction or planning. The principal rivers developed are the Danube, Weser, Mosel, and Main (Renner, 1960). Post-World II developments in West Germany include renovation of plants built in 1925 at Schwabenheim and Kochendorf. The country leads in the use of pumped storage for peaking power (Lottes, 1962).

In 1956 Germany and France agreed upon a pattern for development of the Rhine between Breisach and Strasburg. The new plan reduces canal length from 73 to 40 miles (Seifert, 1959). The layout for the powerhouses remains unchanged from a former plan. The amount of power to be installed was not given.

An interesting storage power station on the Lech, near the frontier between Tyrol and Bavaria, has been completed since 1955 (Haimerl, 1958). The dam is near Rosshaupten, downstream from the waterfall at Fussen. It is earthfill, was chosen to harmonize with the surroundings, rises 134 feet above bedrock, and is adjacent to a powerhouse that contains two sets of 24-MW generators. A picture furnished by Haimerl indicates that the power development does not detract from the beauty of this scenic region.

Greece

The largest development of its kind in Greece has recently been placed in service on the Megdora River by French companies. The first of three 40-MW generators began producing power in 1960. On the Tavropos River a head of 1,970 feet has been developed by a dam at Kavakia Gorge and diversion of water from the Ionian Basin to the Aegean Basin. The 120-MW powerplant was put in operation in 1961. The project includes irrigation of 24,700 acres of land on the Thessaly Plains. Special reinforcements were included in the dam because of frequent earthquakes (Water Power, July 1962, p. 290).

Hungary

The United Nations Economic Commission for Europe (1960) estimated that the gross theoretical waterpower potential at average discharge is 822 MW with 100 percent utilization. The estimate in table 15 indicates that 40 percent of this is technically developable. According to the Commission, 21 percent of the gross potential is economic in Hungary.

No actual development is known to have taken place in Hungary since 1955; however, plans for the exploitation of the Danube from the Czech-Austrian frontier to the Black Sea entail construction of a dam in Hungary near the border with Czechoslovakia. It will raise the water level about 20 feet and create a lake 62 miles long. Ten Kaplan turbines of about 14-MW capacity each will be installed, and locks are planned to provide for barge traffic.

Ireland

A recent estimate places economic potential at 115 MW (continuous). Present installations developed the equivalent of 80 MW (continuous) (World Power Conf., 1962, Preprint 1 I.2/1). The Electricity Supply Board of Ireland is guarding against adverse effects of hydroelectric development on fish (Water Power, Aug. 1959, p. 284). In its 31st annual report the Board reports that waterpower investigations are being made on 17 undeveloped rivers (Water Power, Oct. 1958, p. 364).

A 19-MW unit was put in operation in the Inniscarra plant and an 8-MW unit was commissioned in the Carrigadrohid plant, both on Lee River, during 1957. Cung Dam and powerhouse (4-MW?) were completed during 1958 on the Clady River (Water Power, Oct. 1958, p. 364).

Italy

Economic potential waterpower has been estimated to range from 55 to 65 x 10^9 kwhr per yr (World Power Conf., 1962, Preprint 184 I.2/24). The larger amount equals 7,420 MW of continous power.

Italy has been one of the most active countries in planning and executing waterpower developments since 1955. By the end of 1958, installed capacity was 11,607 MW, an increase of more than 60 percent over 1955. In describing Italian progress, "Water Power" reported in May 1958 (p. 189) that Italy had 70 single-arch dams in service at the end of 1957, 40 of them having been built since World War II; and that 60 underground stations were in operation, most of them built since 1949. An estimated 35 percent of all electric capacity in Italy was installed in underground powerhouses (Water Power, Dec. 1957, p. 443). The principal new power developments have been in the Alpine river basins. Important developments, however, have been carried on in all parts of Italy including Sardinia and Sicily.

The recently completed Vaiont Dam, a cupola arch by the late Carlos Semenza, is the highest completed arch dam in the world (873 feet). The Vaiont damsite on the Vaiont River near its junction with the Piave River is topographically ideal, but the storage capacity of the reservoir (122,000 acre-feet) formed is in sharp contrast with Lake Mead's 30 million acre-feet for a similarly high dam. Vaiont storage is used for seasonal balancing between the Piave and Cellina systems of the Societa Adriatica di Elettricita, which was organized in Venice in 1905 (Water Power, May 1958, p. 181).

A tragic disaster occurred at Vaiont Dam while this report was in preparation for printing. On October 10, 1963 a reported 130 million cubic yards of earth and rock slid into the reservoir causing huge waves of water to flow over the dam. Loss of life in the valleys below the dam (the number still undetermined) ran into thousands and overshadowed the fact that the world's highest arch dam was only slightly damaged by the waves that overtopped it. Early news reports indicate that the dam suffered only crest damage but that its reservoir has been choked off by the slide (Eng. News-Record, Oct. 17, 1963, p. 23).

Another company, Societa Idro Elettrica Atesina, has just completed a 53.2-MW project utilizing water from two tributaries of the Adige River basin in northern Italy (Water Power, Nov. 1957, p. 405). The principal facilities of this project are the Gioveretto Dam and Reservoir and the Lasa supply tunnel and powerplant at Lasa on the Adige. The net head is 3,120 feet, and the flow of 230 cfs operates the single-jet Pelton wheel in the powerhouse.

Azienda Elettrica Municidale of Milan began operating in 1906 and has a concession to develop the Adda River. Grosotto Dam and station on the Adda River in the Italian Alps was completed in 1910 with a capacity of 36.2 MW (Water Power, Mar. 1961, p. 89). The Valtellina project now under construction by this company will include an extensive water-gathering system and two principal storage reservoirs—Giacomo and Cancano of 51,885 and 99,717 acre-foot capacity respectively. There will be five smaller reservoirs and seven powerplants with heads from 3,130 feet (LePrese) to 961 feet (Stazzona). The largest powerhouse, with an installed capacity of 200 MW, will be the one below the Cancano Reservoir near Premadio. The capacity of the Cancano Reservoir is to be increased to 246,456 acre-feet, double the present capacity, by raising the water level to 564 feet. The present dam is a cupola arch, chosen after extensive studies showed it to be the most economic (Water Power, Mar. 1961, p. 93).

The Alto Chiese project of the Edison Group, Milan, is a most impressive development. When completed it will have a total capacity of 342 MW and will be capable of producing about 624 million kwhr annually. The project will have three storage reservoirs and three powerplants. None of the plants is located at a reservoir. Numerous diversions will increase the controlled drainage areas, and there is a complex system of diversions from streams not regulated by reservoirs. In downstream order the reservoirs and their capacities in acre-feet are: Malgabissini, 48,642; Malgaboazzo, 9,566; and Ponte Murandin, 235.

The second stage of development on the Talvera River in Bolzano Province was put in operation in February 1960. Chief features are the Covera and Valdruna balancing reservoirs, which afford reuse of the water if desired, and a two-compartment surge tank that operates like a differential tank to dampen oscillations quickly (Water Power, May 1962, p. 207).

Luxembourg

Luxembourg has installed two new hydroelectric stations on the Sure River since 1955. One of these is a peak-load plant that will operate 4 hours a day. The storage capacity of the reservoir is 42,968 acre-feet, and two 6,400 kva (kilovolt-ampere) Francis sets operate under a head of 120 feet (Water Power, Oct. 1958, p. 364). The first of five pumped-storage sets is now being installed at Vianden. The plant has been planned for 900 MW with pumps totaling 621 MW (Water Power, Sept. 1962, p. 361). This is one of the world's outstanding pumped-storage developments.

Netherlands

The United Nations Economic Commission for Europe (1961) estimates the gross theoretical waterpower potential at average discharge to be 411 MW with 100 percent utilization. The estimate in table 15 indicates that 18 percent of this is technically developable. According to the Commission, there is no economic waterpower in the Netherlands.

Norway

A recent estimate by the Norwegian Watercourse and Electricity Board revises potential waterpower estimates upward. Economically installable capacity is now placed at 16,442 MW—80 percent of the estimated technically feasible power at average discharge. The survey excluded sites of less than 700 kw (Water Power, July 1962, p. 256).

Norway has the highest per capita kilowatthour consumption of electricity of any country in the world (nearly 9,000 kwhr per yr), and more than 99 percent is generated in hydroelectric stations.

The Aura powerplant, completed in 1956, has an installed capacity of 300 MW and operates under a head of 2,558 feet. The generating sets are four 32-MW and three 60MW Pelton wheels. The 60-MW sets are the largest in Norway (Water Power, Sept. 1956, p. 327). The development uses water from two streams, the Lilledalselv and the Aura, which drain an area south of and in the general vicinity of Trondheim. The power is used in the nearby cities and towns and at an aluminum plant at Sunndalsora.

The recently completed Vinstra development between Oslo and Trondheim features an underground station, one of the world's longest supply tunnels, and (until Hemsil's 1,840 feet) the highest head Francis machines in Norway (1,470 feet). The powerhouse site is on the Lagen near the mouth of the Vinstra. Two 50-MW generating sets commenced operation in 1953, a third in 1955, and a final one in 1958. Storage, provided by raising Lake Olstappen, flows to the powerhouse through a 15-mile tunnel. It is understood that by damming Lakes Bygdin, Vinsteran, Sandvann, Heimdalsvatin, Espedalsvann, and Olstappen, and by utilizing storage from many small natural lakes in the basin, the discharge can be completely regulated to provide a mean flow of 1,165 cfs. Running 5,000 hours per annum the production would be about 1,000 million kwhr (Water Power, Mar. 1956, p. 86). Upper Vinstra, an addition to the Vinstra project, was completed in 1959. By interconnecting the lakes of the main Vinstra with Lake Nedre Heimdalsvann, it was possible to add a powerhouse above Lake Olstappen, where 120 MW are installed (Water Power, Sept. 1959, p. 349).

Plans for the future include the Sira-Kvina scheme in southwest Norway, where municipal electric boards have obtained rights to develop the Sira and Kvina Rivers. The total planned installed capacity in several powerplants is 1,360 MW. Also planned is a joint Norwegian-U.S.S.R. venture on the Pasvik River, which forms the border for 70 miles between the two countries. Four plants will be constructed according to a 1957 agreement (Eng. News-Rec. Dec. 18, 1958, p. 53).

Norway's largest hydroelectric power project is currently being built on the Tokke and Vinge Rivers. Three powerplants having a combined capacity of 810 MW will be built.

Poland

The United Nations Economic Commission for Europe (1961) estimates the gross theoretical waterpower potential at average discharge to be 3,642 MW with 100 percent utilization. The estimate in table 15 indicates that 33 percent of this is technically developable. According to the Commission, 17 percent of gross potential is economic in Poland.

Portugal

An IBM 650 computer was used to determine details of the alto-Rabagao Dam. This is one of the final dams in the Cavado-Rabagao development. The Cavado-Rabagao project consists of four reservoirs on the Cavado River and two on the Rabagao. The reservoirs on the Cavado are: Alto-Cavado, Paradela, Salamonde, and Canicada. On the Rabagao the reservoirs are the Alto-Rabagao and the Venda Nova. Interconnecting tunnels between the high reservoirs of the two rivers make it possible to utilize the maximum amount of water through the greatest possible head. The highest head in the group is 1,509 feet at Paradela.

The Duro River rises in the Urbion Range in Spain and discharges into the Atlantic Ocean at Oporto in Portugal. The river marks the boundary between the two nations for about 62 miles. By agreement, each country is developing about half of the 1,320 feet of fall along the international section—Portugal developing 674 feet of head upstream from the Tormes River and Spain developing 656 feet downstream. Portugal has three projects that develop head by dams but all operate chiefly as run-of-river plants—Miranda (187 feet), Picote (226 feet), and Bemposta (225 feet). Spain has two plants, Villal Campo and Castro. An ingenious feature of the design for the Picote station is that the tailrace discharges underneath the apron of the ski jump spillway. This was made necessary by the nature of the terrain (deep, narrow canyon), and the fact that floods of very high capacity pass down the river. The dam is double-curvature arch and the ski jump spillway is separate from the dam. The powerhouse is underground. Portugal has four plants at dams on the Duro downstream from the international section (Pocinho developing 66 feet of head, Valeira developing 102 feet, Regua developing 89 feet, and Carrapatelo developing 118 feet) (Water Power, Apr. 1959, p. 129).

Romania

The United Nations Economic Commission for Europe estimated the gross theoretical waterpower potential at average discharge to be 7,306 MW with 100 percent utilization. The estimate in table 15 indicates that 41 percent of this is technically developable. According to the Commission, 34 percent of the gross potential is economic in Romania.

Spain

Several companies generate and distribute electricity in Spain but transmission grids are interconnected 132 kv and 220 kv lines (Pineyro, 1960).

Power from a recently completed project, Eume, on the Eume River in northwest Spain, will be used in La Coruna Vigo. The Eume River drains an area of 193 square miles, which receives an average of 39.4 inches of rainfall. The Eume reservoir will hold 99,149 acre-feet of water (about one-half of the average annual runoff). The powerhouse is not connected with the dam and is above ground. It has an installed capacity of about 55 MW and operates under a gross head of 213 feet (Pineyro, 1960).

Spain is making steady progress on its plan to complete an entirely integrated system within the drainage basin of the Ribagorzana River. This river is 81 miles long and drains an area of 786 square miles. Its headwaters are at an altitude of about 9,840 feet, and the tailrace of the lowest plant is at an altitude of about 1,000 feet. Water downstream from the latter point will be used for agricultural purposes. When the project is completed, the basin will have 13 powerplants with a total installed capacity of about 500 MW (Water Power, Jan. 1958, p. 34).

The flows of Spanish rivers are variable and large floods often pass down narrow canyons. An unusual station design has resulted. The recently completed Salime plant on the Navia River in northwestern Spain has placed the powerhouse underneath the spillway (similar to Picote in Portugal) so that high floods will pass directly over the powerplant. With the completion of Salime, the Navia River has two reservoirs—Salime (243,213 acre-feet), and Doiras (87,556 acre-feet). Upstream from Salime a projected plant, Suarna, will have a storage capacity of 95,663 acre-feet, and a small downstream reservoir, Arbon, also projected, will have a capacity of 25,942 acre-feet (Water Power, July 1957, p. 267).

Sweden

Many estimates have been made of Sweden's economically exploitable waterpower, and each succeeding inventory gives a higher figure than the preceding ones. In 1923 annual capability was estimated at 32.5 twhr (trillion-watt hours) (32.5×10^9 kwhr). An inventory made in 1955 increased this to 80 twhr. Technical progress and more complete knowledge of water supplies are both factors in this increase of nearly 250 percent (Berglund and Larsson, 1959). The gross resources have also been estimated several times. In 1930 Sweden's hydraulic-power resources were reported equal to an average output of 15,860 MW at 100 percent efficiency. This would equal 139 twhr. The same estimator increased the average kilowatts to 17,820 MW or 156 twhr (Melin, 1957).

Assuming that the estimate was still too low, Berglund and Larsson made a new study by two methods recommended by the Economic Commission for Europe. In the first method the rivers were divided into three surface sections, with a gaging station at the downstream point in each section. In the second method the runoff in cubic meters per second was applied to the average altitude of the area in meters by the formula, power = 9.81 x runoff x altitude. Runoff data were based on gaging station records of 10 to 125 years. Including the Swedish share of the Trone, the estimators arrived at a figure of 196.1 twhr per yr, of which 80 twhr are considered economically developable. This is 43.4 percent of the total natural resource. The study revealed that Sweden's principal hydroelectric resource is in the north and that it is considerably greater during summer than during winter months.

The following tabulation shows the average discharge, in cubic feet per second, of Sweden's five largest rivers:

Gota	20,305
Lule	18,010
Angerman	17,304
Indal	16,245
Ume	15,609

The "typical" river in Sweden rises out of a lake or cluster of lakes and flows southeast across the country to the Gulf of Bothnia.

The Lule is a typical river and is said to have Sweden's largest remaining hydropower resource (over 16 billion kwhr). Plans for developing this potential include enlargement of 15 of the basin's 75 lakes (Water Power, Feb. 1961, p. 47). The Messaure plant, now being developed on the Lule, will eventually be Sweden's largest power station and will include a rockfill dam 328 feet high and 5,905 feet long having a volume of 13,733,400 cubic yards (Water Power, Dec. 1959, p. 442).

The Ume, located in north-central Sweden, furnishes water for Sweden's largest power station, Stornorrfors (installed capacity 375 MW, ultimate capacity 500 MW). Other power stations on the Ume and their installed capacities in megawatts are:

Harssele	200	Lower Bjurfors	72
Tugen	96	Pengfors	50
Grundfors	88	Stensele	48
Umluspen	88	Upper Bjurfors	42
Balforsen	82		

Sweden produces 53 percent of its hydroelectric power in underground stations, leading all countries. There are 30 plants with a total installed capacity of 3,650 MW and 17 additional underground stations (1,600 MW) will be added by 1966 (Water Power, Jan. 1962, p. 25).

In Sweden stations are usually placed underground for reasons of economy. The underground plant might be chosen also to preserve an area's scenic and recreational values, achieve greater head, attain larger plants, and reduce maintenance and depreciation costs. A recent innovation, placement of the powerhouse directly under the water reservoir, eliminates the necessity for a surge tank. Tunneling can be done more cheaply in some places by shortening the more expensive approach tunnel and lengthening the less expensive (possibly unlined) tailrace tunnel.

Sweden is also a leader in transmission-line and tunneling technology.

Switzerland

In Switzerland, as in Norway, 99 percent of all electric energy is produced in waterpower plants (World Power Conf., 1962, Preprint 148 I.2/18). The United Nations Economic Commission for Europe (1961) estimates the gross theoretical waterpower potential at average discharge to be 16,438 MW with 100 percent utilization. The estimate in table 15 indicates that 44 percent of this is technically developable. According to the Commission, 21 percent of gross potential is economic in Switzerland. Within 10 years almost all economic sites are expected to be developed (World Power Conf., 1962, Preprint 148 I.2/18).

One of the most widely publicized power developments of recent years is Grande Dixence in the Rhone River basin. Grande Dixence is the world's highest completed dam. It rises 922 feet above its lowest foundation, about 200 feet higher than Hoover Dam. The reservoir has a 322,000 acre-feet capacity, is 7,700 feet above sea level, and supplies 800-MW powerplants in two locations under a total head of about 6,000 feet (Turner, 1959).

As development of Alpine hydroelectric resources progresses, more use is made of multiple diversions and conduits to central locations for development of power. The best example of this is the Mauvoisin project, which includes 777-foot high Mauvoisin Dam on the Darnse de Bagnes, a Rhone tributary. In addition to the Darnse, five smaller watersheds are diverted into the reservoir and runoff from 8.2 square miles is collected below the dam to make a total drainage area of 72.7 square miles. Glaciers cover 41 percent of the drainage area and tend to equalize flow. The water is used in the Fionnay and Riddles plants, which have 127.5 MW and 335 MW installed under heads of 1,540 feet and 3,320 feet, respectively (Portland Cement Assoc., 1962). Another example is the addition in 1958 of the Gabi plant to the Simplon River basin development, which previously consisted of a 36-MW plant at Gondo near the Swiss-Italian border. The Gabi plant has 12 MW installed. Water-gathering facilities tap drainage basins of 13, 4, and 6 square miles. The last two are about one-third glacier covered. The intake structures feature automatic desanding equipment (La Houille Blanche, May-June 1961, p. 225).

The 492-foot Zervreila Dam on the Valser Rhein is representative of present Swiss arch-dam engineering. When completed in 1957, it was the highest arch dam that had been built in Switzerland since World War II and was one of 14 dams more than 328 feet high built during this period. The reservoir holds 81,000 acre-feet of water. The Zervreila Reservoir is the principal storage of a three-station power project with a combined capacity of 246 MW. The Zervreila plant has an installed capacity of 60 MW and is equipped with 6-MW pumps for pumped storage (Schnitter, 1961).

Two recent developments on the Leinne River are the first in that basin since 1917. An earlier plant on the lower Leinne was built in 1907. The two new projects combine to develop a head of 4,185 feet. The upper stage has a head of 2,801 feet and an installed capacity of 54 MW using 265 cfs. The downstream development operates under a gross head of 1,368 feet with a flow of 300 cfs, and a capacity of 28.6 MW. The upper plant utilizes water from the Zeuzier Reservoir through a tunnel and pressure shaft in an underground powerhouse at Croix. A balancing reservoir, an additional tunnel, and a penstock lead to the downstream powerhouse at St. Leonard on the Rhone (Philippin, 1955).

A development on the Hinterrhein, which involves tributaries in Italy, has been carried out as an international project. Twenty percent of its costs are paid by Societa Edison Milano, and the rest by Swiss power concerns. The project includes three powerplants: Ferrera (185 MW and a 48-MW pump), Barenburg (215 MW); and Sils (230 MW). The scheme will produce 1,325 million kwhr per yr including 59 million kwhr from pumped storage during the summer months (Kalt and Baden, 1957).

A Swiss-Italian reach of the Inn, a tributary of the Danube, is being developed under an agreement with Italy that makes it possible to develop and operate the project as a Swiss enterprise. The Lavigno Reservoir (145,927 acre-feet) will be developed by a 394-foot high arch dam. A tunnel 24,928 feet long and a pressure shaft 3,444 feet long will serve a powerplant with 400 MW installed capacity, and a 28-MW pumping plant at Ova Apin (Water Power, Feb. 1958, p. 80).

Small plants are still being built in Switzerland. Merzenbach, on a Rhone tributary, has a maximum output of 1.89 MW using water from a drainage area of only 2.7 square miles. The head is 1,650 feet (Garlet, 1961).

U.S.S.R.

The U.S.S.R. has about 100,000 streams over 6 miles in length whose total length is 1,860,000 miles. Four of these are among the 15 largest rivers in the world. In order of average discharge, shown in cubic feet per second, they are as follows:

Yenisei	614,000
Lena	547,000
Ob	441,000
Amur	388,000

There are 250,000 lakes and 775,000 square miles of swamp area. The potential energy of the rivers is more than 400 million kw, of which 80 million is in small and medium-size rivers. Of the potential power of the U.S.S.R., at least 85 percent reportedly is in Siberia (Grossen, 1958). Lake Baykal, which empties into the Angara River and thence into the Yenisei, is the largest lake in Siveria. The lake is situated at an altitude of a little less than 3,000 feet above sea level and is 5,700 feet deep. It covers an area of about 12,150 square miles and is a collection center and regulator for more than 300 streams. This situation gives the Angara and Yenisei very favorable positions among streams having waterpower potential.

The U.S.S.R. added 5,500 MW in 1956 and reportedly has increased yearly the installation rate since that time. By 1963, the installation rate is scheduled to reach 10,000 MW per yr (Grossen, 1958). Between 20 and 30 percent of all installations probably are waterpower in the U.S.S.R. at the present time. Hydroelectric stations account for about 20 percent of the present energy production (Sweet, 1962).

The highest dams in the world are now under construction in the U.S.S.R. The Nurek Dam (rockfill, 984 feet high) on the Vakhsh River, a tributary of the Amu Darya, will have an outdoor plant of 2,700-MW capacity in nine units of 300 MW each. It is planned to top this by a double-curvature arch dam (Ingurskaya Dam, 988 feet) on the Ingura River, a Black Sea tributary. Ingurskaya will have an underground plant of 1,400 MW from six 233-MW units (Bowman, 1962b). Between 1955 and 1962 the U.S.S.R. completed, or was working on, five reservoirs capable of storing more than 30 million acre-feet of water (table 2).

The Volgograd (Stalingrad) station was officially opened in September 1961 by Premier Nikita Krushchev. The station has 22 Kaplan turbines operating under 72 feet of head with nameplate ratings increased from 105 to 115 MW or 2,530 MW in all. The Bratsk station, planned to have 4,500 MW installed, is in partial operation on the Angara River; and Krasnoyarsk station, on the Yenisei, is planned to have an installed capacity of 6,000 MW. A 500 kv transmission line will carry power from these plants to Moscow (Water Power, Nov. 1961, p. 421). On the Ob River a 400-MW plant is nearing completion near the city of Novosibirsk. The powerhouse consists of seven bays each housing a 57.5-MW vertical set driven by an adjustable blade Kaplan turbine with a 26-foot diameter (Water Power, April 1958, p. 159).

In 1961 the U.S.S.R. began construction of its first pumped-storage plant, Zagorsk, north of Moscow. It will operate under a head of 295 feet and will have capacity 585 MW installed (UNIPEDE, 1961, 2e Trimestre, p. 53). The U.S.S.R. Has made extensive studies of direct-current transmission and operates the world's highest voltage alternating-current line—525 kv between Stalingrad and Moscow. A transmission line carrying 800 kv is planned for the Urals (Water Power, Nov. 1961, p. 421). A project now under construction near Turkey and Iran will reduce evaporation losses by lowering Lake Sevan 65 feet in 50 years to decrease its water surface area (Brown, 1962).

United Kingdom

Hydroelectric development is confined to North Scotland and North Wales (World Power Conf., 1962, reprint 142 1.2/16). The North of Scotland Hydroelectric Board was organized in 1943, and since then has been actively planning and constructing power developments in its area of jurisdiction. Some power projects of very modern and detailed design have recently been completed under its direction. The Garry and Moriston developments in Ivernessshire are representative of the Board's work.

Both the Garry and the Moriston Rivers are tributary to lakes on the Oich River. The 147-square-mile Garry drainage basin development includes: the Quoich Dam (rockfill), which raises the lake level 100 feet; a 12,843-foot pressure tunnel; the Quoich power station (gross head 330 feet); the Invergarry Dam; a 14,033-foot tunnel; and the Invergarry power station (gross head 174 feet). The Moriston, directly north of the Garry, drains 155 square miles. Its development pattern is very similar to that of the Garry, but there are two upstream reservoirs for the Ciannacroc powerplant. These reservoirs, the Loyne and Cluanie, are connected by a 7,600-foot tunnel. An additional 14,000-foot tunnel and a high-pressure shaft lead to the Ciannacroc powerplant. The Dundreggan Reservoir, nine miles downstream, regulates the stream and a high-pressure intake shaft takes water from the reservoir to the Glen-Moriston powerplant. The most unusual feature of this plant is the 22,000-foot tailrace tunnel between the powerplant and Lochness.

Each of the Garry powerhouses has an installed capacity of 22 MW. The installed capacities of the Moriston plants are 22MW and 36 MW in downstream order. Ciannocroc powerhouse has units of 4 MW and 18 MW. The Glen-Moriston powerhouse has two 18-MW units (Water Power, July 1959, p. 247).

Fish protection and propagation are included in the Garry and Moriston plans. On the Garry River, fish can swin as far upstream as the Quoich powerplant, where they are trapoed and their eggs taken and incubated during the winter months. On the Moriston River fish can swin up to Cluanie. There they are trapped and their eggs are incubated in the Moriston below the dam. An interesting experiment is being carried on in the area downstream from the incubation sites. The river has been partly closed with gabions to make it run deeper during low water periods to facilitate fish migration (Water Power, July 1959, p. 253).

Probably the outstanding project in the British Isles is the recently completed Ffestiniog pumped-storage plant in North Wales. The plant has four 75-MW English Electric water-turbine generator and pump sets. These Francis turbines operate at the highest head of any in the country—1,050 feet. Separate pumps and generating sets are connected to common electric machines (Water Power, Feb. 1961, p. 45). At Cruachan, on Loch Awe, the world's highest head (1,206 feet) pump turbines are being connected to 100-MW motor generators (Water Power, Aug. 1963, p. 315).

The cross-channel direct-current transmission cable now links the predominantly coal-fired generators of England to the French network, which is substantially supported by waterpower.

Yugoslavia

The United Nations Economic Commission for Europe (1961) estimates Yugoslavia's gross theoretical waterpower potential at average discharge to be 23,505 MW with 100 percent utilization. The estimate in table 15 indicates that 43 percent of this is technically developable. According to the Commission, 66,500 million kwhr, 32 percent of the gross potential, is economic in Yugoslavia. This equals 7,600 MW at 100 percent utilization. The economically-possible hydroelectric potential in Yugoslavia has also been estimated at 60 billion kwhr (6,800 MW at 100 percent utilization) (Korosec, 1960). The principal projects would be on the Drava, Save, Soca, Mura, and Kolpa Rivers. Korosec estimated that only about 15 percent of the available resources are presently developed. From 1945 to 1959 the total installed capacity increased from 220 to 648 Mva (Megavolt-amperes).

Heavy rainfall and high mountains have endowed Yugoslavia with abundant waterpower—as great as that of Italy according to some estimators. In contrast with the extensive development in Italy, Yugoslavia has to date developed only 10 to 15 percent of its total waterpower resource. Some progress is being made, nevertheless. In 1939 thermal generation was leading hydroelectric 672 million kwhr to 478 million kwhr. The figures for 1956 show that hydroelectric energy, at 2,869 million kwhr, was more than double thermal production, which was 1,178 million kwhr (Water Power, Oct. 1958, p. 401).

The Yugoslav-Adriatic coast from Rigeka to the Albanian border (the Karstic region) receives ample precipitation, but streams are short and flashy, with discharge principally during winter. In contrast, the Drava River in the north of the country has its greatest discharges in summer following the thaw in the Alps. By coordinating these two regions the energy production could be balanced, and because of the relatively low demand some energy might be exported (Szavits-Norsan, 1960).

Projects presently underway include the Dravograd-Maribor pier-type power stations. The Fala plant erected in 1918 and enlarged in 1926 and 1931 is being supplied with an additional 18-MW generating set to increase its installed capacity to 54 MW. The Mariborski plant is also having a third set installed. The plants on the lower Drava (Maribor Ormoz reach)—Loka, Hajdose, Borl, and Ormoz Rivers—are conventional run-of-river plants. Their diversion works also serve water-supply and irrigation purposes (Korosec, 1960). A review of Korosec's article on progress in Slovenia was published in "Water Power" for October 1961 (p. 415). The country has recently received a loan from the World Bank to finance a 216-MW plant near the Adriatic coast together with transmission lines. The plant (Senj) will use water from the Velebit Mountains' Gacka and Lika Rivers. An arch dam will create a storage reservoir on the Lika, and there will be 20 miles of tunnels (Water Power, Apr. 1961, p. 127).

The Iron Gate reach of the Danube, development of which will require cooperation between Yugoslavia and Romania (formerly a problem of Austria and Hungary), could supply much-needed energy for speeding up industrialization. A head of about 98 feet could be developed, and installation of as much as 870 MW has been considered. The Danube narrows and flows rapidly through the reach, and there are no great technical difficulties. Completion of the project is not anticipated before 1970 because of the international situation, and because the demand for power is not too great at this time. Development of this reach of river would be a great aid to navigation (Partl, 1960). A review of Partl's article was published in "Water Power" for November 1960 (p. 451).

Yugoslavia put its first pumped-storage plant in operation in March 1957 as part of the Vinodol project. The plant uses water from the Lokvarda and Licanka mountain streams. Some of its features are: a 154-foot earthfill dam; a reservoir of 24,727 acre-feet; the Kriz pumping plant, which lifts the water 79 feet; and three 35-Mva generators driven by Pelton turbines (Einwalter, 1957).

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