Historical Review of the International Water-Resources Program of the U.S. Geological Survey 1940-70

GEOLOGICAL SURVEY PROFESSIONAL PAPER 911

Prepared with the cooperation of the Agency for International Development, U.S. Department of State, and international organizations

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By GEORGE C. TAYLOR, JR.

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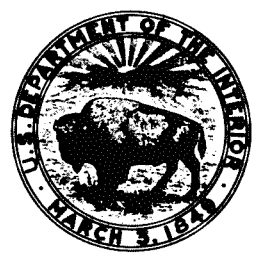

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HISTORICAL REVIEW OF THE INTERNATIONAL WATER-RESOURCES PROGRAM OF THE U.S. GEOLOGICAL SURVEY 1940-70

By GEORGE C. TAYLOR, JR.

ABSTRACT

The present review describes the history of the U.S. Geological Survey's (USGS) activities in international water-resources investigations and institutional development as well as exchange in scientific and applied hydrology during 1940–70. The bulk of these activities has been carried out under the auspices of the U.S. Department of State, U.S. Agency for International Development and its predecessors, the United Nations and its specialized agencies, and the regional intergovernmental agencies. The central objectives of the USGS' international water-resources activities have been to strengthen the administrative, staff, and operational functions of counterpart governmental hydrological and water-resources agencies; to improve the skills and capabilities of host-country scientific, engineering, and technical personnel; to exchange research specialists and publications in the sharing of advances in hydrological knowledge and methodology; and to participate in mutually beneficial international organizations, symposia, conferences, seminars, and special programs dedicated to various aspects of scientific and applied hydrology.

As the USGS is a domestic agency, its activities outside the United States must be covered by legislative authorization. Enabling legislation in force in 1970 included Public Laws 80–402, 85–743, 85–795, 87–195, 87–256, 87–626, and 91–175 of the U.S. Congress. USGS water-resources activities in the U.S. bilateral program were financed at an average level of $525,000 during 1950–70, peaking at $1,400,000 in fiscal year 1966. This funding is exclusive of counterpart funds in other currencies provided by foreign governments in support of project costs.

Between 1940 and 1970, USGS hydrogeologists, water chemists, engineers, and hydrologists completed 340 short- and long-term project-oriented international assignments in some 80 host countries. During the same time more than 428 water scientists, engineers, and technicians from 60 countries have received academic and in-service training through USGS water-resources facilities in the United States. Also in this period some 336 reports of a technical and scientific nature have resulted from water-resources projects in the U.S. bilateral program.

The USGS as of 1970 had been participating in international water-resources technical assistance projects for almost three decades and since the early 1960's also has been deeply involved in international exchange related to scientific and applied hydrology. Political events and age-old social and cultural constraints have presented many obstacles to goals of building viable hydrologic and water-resources institutions in the developing countries. Nevertheless, significant advances have been made in many of these countries which the USGS helped to achieve. Also between 1965 and 1970 the USGS played an active role in UNESCO's International Hydrological Decade, which already has had a marked impact in sparking advances of hydrologic knowledge among the developed countries as well as in the application of the scientific method to the solution of water problems in the developing countries.

INTRODUCTION

"History's highest function is to rescue merit from oblivion, and to hold up as a terror to base words and actions the reprobation of posterity."

Tacitus

Historiae, ca. 116 A.D.

The present historical review of the role of the U.S. Geological Survey (USGS) in international water-resources investigations and institutional development as well as exchange in scientific and applied hydrology is based on the writer's experience and association with the program over a period of 30 years. The review is largely descriptive and does not pretend to present an analysis of the philosophic import of technical assistance and scientific exchange—either in water-resources appraisal, development and management or in scientific and applied hydrology. Moreover, the review does not attempt to cover the full gamut of the USGS international activities but only those that pertain to water-resources investigations and hydrology. Emphasis in the review is on the participation of the USGS water scientists and engineers in the U.S. bilateral program, because this, historically, has constituted the bulk of the total overseas USGS water-resources activity and is the part with which the writer is most familiar. The review, however, describes, in somewhat less detail, USGS participation in activities of water-oriented multilateral agencies of the United Nations family and regional intergovernmental agencies; governmental scientific and technical exchange and cooperation; nongovernmental interna-

tional organizations; investigations and research abroad in extension of domestic research; foreign participant education and training; and procurement of hydrologic equipment for overseas projects. The review covers perhaps 90 percent of the USGS overseas water-resources activity during 1940–70 but not that of activities for which little or no available documentation exists.

The USGS has had in its basic charge topographic and geologic mapping and the scientific appraisal and evaluation of our Nation's mineral and water resources since its establishment in 1879. From its earliest days, moreover, USGS scientists and engineers have maintained active professional contacts and exchanged ideas, concepts, and knowledge with their counterparts in countries around the world through correspondence, publications, individual travel, and attendance at international scientific meetings. Thus, the USGS has always been internationally oriented, even though its primary mission is within the national boundaries of the United States and its possessions.

During the last years of the 19th century and the first four decades of the 20th, USGS water scientists and engineers were assigned from time to time to overseas activities under special bilateral agreements, notably in Brazil, Haiti, the Dominican Republic, Cuba, Panamá, and Nicaragua. Active involvement of U.S. Federal agencies, including the USGS, in overseas programs was first formalized, however, by President Roosevelt's creation in 1938 of the Interdepartmental Committee on Scientific and Cultural Cooperation (ICSCC) under the direction of the Department of State. ICSCC activities were authorized and financed under the terms of Public Law 63, 76th Congress, May 25, 1938, and Public Law 355, 76th Congress, August 9, 1939. The ICSCC, designed to coordinate the overseas programs of some 26 departmental and independent Federal agencies, was active throughout the 1940's until its mergence in 1950 with the programs of U.S. Technical Cooperation Administration (TCA).

Under the aegis of the ICSCC, USGS expertise in resources appraisal and evaluation was first projected overseas during World War II (1939–45), when, as a result of critical shortages of strategic mineral commodities in this country and among our allies, the USGS was authorized to undertake reconnaissance mineral exploration and appraisals in Latin America. Between 1940 and 1946 more than 60 USGS geologists in 16 Latin American countries carried out more than 100 field studies of 11 different mineral commodities that were then in short supply. Also, during the war, some 10 water geologists and engineers from the USGS entered military service and were assigned to engineering groups and water-supply battalions of the U.S. Armed Forces to study water-resources problems and to locate suitable water supplies for military installations in various places in Europe, Africa, Asia, South America, and the Pacific Islands. Little of this work, however, is documented in available form and is not included in the descriptive sections of this report.

Another forerunner of the present U.S. bilateral foreign aid program was the Office of the Coordinator of Inter-American Affairs (OCIAA) founded under the sponsorship of the Rockefeller Foundation. The OCIAA was moved under the wing of the ICSCC in the Department of State during the early years of World War II to further the objectives of President Roosevelt's Good Neighbor policy in Latin America. The OCIAA was reorganized and expanded during the post-war period in the Institute of Inter-American Affairs (IIAA) which provided technical assistance chiefly in education, public health, sanitation, and agriculture during 1945–50. Under the auspices of OCIAA and IIAA, USGS hydrogeologists were involved intermittently through the war and post-war years in appraisals of potential ground-water sources for public and rural water supply and for irrigation in Central America and the Antilles.

During the strife of World War II was born the concept of the United Nations (U.N.) system. Founded in 1945, the UN, during the next few years, gave birth to a large family of intergovernmental cultural, scientific, technical, and development agencies concerned with the social and economic betterment of mankind. Concurrently, the United States was expanding its bilateral program, under the direction of the ICSCC, of cultural, scientific and technical cooperation with friendly developing nations.

During the later 1940's the programs fostered by this committee were directed chiefly toward the Latin American nations, although cooperative projects in selected countries of the Eastern Hemisphere were also included, chiefly under the aegis of the Economic Cooperation Administration (ECA) during 1948–50.

The USGS participation in the activities of the UN and its specialized agencies during their formative years of the late 1940's was relatively small. In the U.S. bilateral program under the ICSCC, however, U.S. Geological Survey personnel worked actively with host-country scientists and engineers in improving their professional competence in miner-

als and water-resources investigations, and in building up the standards of geological and hydrological institutions in 12 Latin American countries as well as in Greece, Korea, Liberia, the Philippines, Saudi Arabia, and Thailand.

With the promulgation of President Truman's Point IV doctrine set forth in his Presidential Message of January 1949, the United States commitment to technical assistance, institutional building, and economic aid in the developing countries became worldwide, not only through a consolidated U.S. bilateral program but through the multilateral programs of the UN and the regional intergovernmental agencies as well. Since 1950 the U.S. bilateral program has continued through several transformations, resulting from shifts in the orientation of U.S. foreign policy. First launched in late 1950 as the Technical Cooperation Administration in the U.S. Department of State with emphasis on technical assistance and institutional development, the program was reorganized briefly in the Mutual Security Administration (MSA) during 1951–53, then in the Foreign Operations Administration (FOA) in 1953–55 and later the International Cooperation Administration (ICA) during 1955–61 under President Eisenhower. The most recent reorganization occurred in 1961 during President Kennedy's administration when ICA was transformed into the present U.S. Agency for International Development (US AID) with emphasis on capital development. Also, at this writing (1970) another reorganization is under consideration based on the recommendations of President Nixon's task force on foreign aid headed by Rudolph Peterson.

The multilateral programs of the UN family grew slowly during the 1950's but expanded rapidly in the 1960's owing to the increasingly pressing needs for social and economic assistance in the developing countries and to shifting emphasis from bilateral to multilateral assistance in many recipient countries. As of 1970, the programs of the UN family were operating at peak manpower and funding levels, whereas the U.S. bilateral program had shrunk to its lowest level since 1948. Historically, USGS participation in multilateral projects has been limited largely to short-term programing, consultative, or technical support assignments. The initiation in 1965 of the International Hydrological Decade (IHD) under UNESCO leadership marked the beginning of a sharp expansion of USGS participation in water-related symposia, working groups, seminars, conferences, and training courses sponsored by international agencies.

Under the aegis of US AID and its predecessors, the agencies of the UN family, other regional intergovernmental agencies, and direct government-to-government agreements, the USGS has actively participated through the years in overseas technical assistance in water-resource investigations and scientific exchange in hydrology, not only in the developing countries but in the developed countries as well. Between 1940 and 1970, USGS hydrogeologists, water chemists, engineers and hydrologists completed 340 short- and long-term project-oriented overseas assignments in some 80 host countries. These water scientists and engineers have worked with a wide variety of host-government organizations including geological surveys, hydrological investigative and research services and institutes, hydropower and flood-control agencies, agricultural and irrigation departments, water-development and land-reclamation authorities, and health and sanitation or public water-supply agencies. During the same time more than 428 water scientists, engineers, and technicians from 60 countries have received academic and in-service training through USGS facilities in the United States. Many of these former participants have assumed positions of leadership within their own governmental organizations. Others have gone into private enterprises for water-resources appraisal, development and management or university programs of hydrological research, education and training. Virtually all have continued professional contacts with the USGS as well as with related resources-oriented public and private organizations in the United States.

ACKNOWLEDGMENTS

Recognizing the mutual dependence of the various sectors of the USGS overseas and domestic programs, the writer, who as of 1971 was Chief of the Office of International Activities (OIA) for the water-resources program, gratefully acknowledges the inspiration, encouragement, and support he has received through the years from his U.S. Geological Survey colleagues. The writer is first constrained to mention those who have been most concerned continually or who have contributed perhaps most significantly to the objectives of USGS overseas water-resources investigations as well as to scientific and applied hydrology. Notable among the many individuals, who have been involved, are the late W. D. Johnston, Jr., the doyen of the USGS overseas program, who introduced the writer to the joys and mysteries of working in Chile, Haiti, Panamá, Thai-

land, and India; the late A. N. Sayre, who had the courage to select the writer as his assistant for his first foreign assignment in El Salvador; T. E. Eakin, who organized the Foreign Hydrology Section (the forerunner of OIA) and guided its course for the first 8 years of its history; F. E. Clarke, whose personal participation and enthusiasm for the OIA program have given it continuing impetus during the past 10 years; R. L. Nace, a founding father and mentor of the International Hydrological Decade, which has created a global view of scientific and applied hydrology; H. E. Thomas, whose philosophic insights into the water problems of the developing countries and their socio-economic implications have given substantial guidance to the OIA, particularly in the U.S. bilateral programs in Africa and western Asia; and last but not least A. I. Johnson, who through his sustained enthusiasm for foreign trainees and understanding of their needs and capabilities, has been a bastion of strength for the OIA foreign participant training program.

In the mundane sphere that relates to the genesis and nurture of overseas projects and foreign participant training, the writer is much indebted to J. A. Reinemund, Chief of the Office of International Geology, USGS, and to G. L. Schoechle, H. L. Fleming, Gertrude W. Brown, and Caroline A. Watkins of his staff for their continuing support and counsel in the operational problems of the OIA. To the loyal staff of OIA the writer must also express his gratitude for enduring support of the program. Those most recently involved have included G. W. Edelen, Jr., Assistant Chief, OIA; Rebecca A. Williams, Foreign Participant Assistant; G. M. Bradford, cartographic technician; and Mildred M. Dunbar and Virginia M. Briggs, secretary-typists.

Of course, many other individuals in the USGS, US AID, the Department of State, the United Nations agencies, and counterpart agencies in foreign governments, have supported and furthered the objectives of the USGS foreign water-resources program. Regrettably, their names are too numerous to mention, but to these anonymous ones the writer also expresses his great appreciation and gratitude, particularly for their help in the operations and program objectives of OIA.

GENERAL OBJECTIVES AND POLICY

During the past three decades through the U.S. Department of State, US AID and its predecessors, the United Nations and its specialized agencies, and the regional intergovernmental agencies, the central objectives of USGS water-resources work in the developing nations have been (1) to strengthen administrative, staff, and operational functions of counterpart governmental hydrological and water-resources agencies, and (2) to improve the skills and capabilities of host-country scientific, engineering, and technical personnel so that they may better direct and guide the investigation, development, and management of water resources—all in support of advancing national economies. With not only the developed nations but also with many developing nations, USGS objectives have been largely directed toward (1) exchange of research specialists and publications in the sharing of advances in hydrological knowledge and methodology, and (2) participation in mutually beneficial international organizations, symposia, conferences, seminars and special programs dedicated to various aspects of scientific and applied hydrology.

In the furtherance of these objectives the USGS (1) has trained foreign water scientists, engineers, and technicians either in USGS domestic field offices and laboratories or by on-the-job training from USGS water scientists and engineers on overseas assignment, (2) has provided hydrological experts to guide, conduct, and participate in international symposia and seminars in scientific and applied hydrology, (3) has exchanged research specialists and shared knowledge in scientific and applied hydrology, (4) has provided direct advisory services through overseas assignments of USGS personnel for the establishment or improvement of operating host-country hydrological and water-resources organizations and institutions, (5) has participated jointly with host-country water scientists and engineers in field and laboratory projects designed to appraise, explore, and evaluate indigenous water resources and water problems, and finally (6) has advised, supported, encouraged, and instructed in institutions and professional societies dedicated to programs of hydrological education and research.

Owing to the complexity and diversity of the international activities of the USGS, no comprehensive statement of policy has been formulated that adequately covers all phases of these activities. An interim statement, however, approved by the Director of the USGS in April 1963 is quoted below:

> In accepting proposals for activities in foreign areas, as well as in domestic work for other agencies, the Survey feels that among the advantages to the agency requesting the work is the ability of the Survey to apply world-wide professional perspective, to select appropriate personnel from its large reservoir of trained specialists, to make available appropriate equipment from its rather complete stock, and to be able to

support its work with such specialized professional and technical services as may be required.

The Survey is fully cognizant of the rapidly expanding responsibilities of the United States toward the development of foreign areas. This responsibility is not only toward a better economic level for the people of those areas but is a realistic effort toward obtaining raw materials and products for use by this country and other countries of the free world. Although limited by an insufficient number of trained personnel not already assigned to high-priority projects, the Survey recognizes the need for expanding part of its efforts in foreign areas and in training foreign nationals and willingly accepts appropriate responsibilities in such activities. Because of competence in its special fields, the Survey must reserve the right to appraise carefully the requirements and special advantages of foreign projects in order to balance them against domestic activity and thereby to determine relative priorities.

With respect to such work undertaken, it is Survey policy to assign experienced personnel from the domestic program on a rotation basis. In instances where particular specialists are needed which are temporarily unavailable from domestic rolls, the Survey engages, on excepted appointment, specialists from universities or private industry. Paramount to all projects, however, is the principle of transferring philosophically, industrially, and scientifically the concept of central government geological services to the public and national welfare.

LEGISLATIVE AUTHORITY

As the USGS is a domestic agency, its activities as related to surveys, investigations, and research outside the United States must be covered by special legislative authorization. Attendance at international scientific meetings is permitted under the Training Act (Chapter 41, Title 5, U.S.C.), and conferring with individuals relative to domestic program activities is permitted under the Organic Act of the USGS; all other USGS activities abroad are permitted only as a result of other enabling legislation which is described below. Under the Organic Act of March 3, 1879 (20 Stat. 394; 43 U.S.C. 31), of the USGS and in pursuance of later specific enactments, authorized activities of the USGS are restricted territorially to the "national domain," United States territories and possessions, Antarctica, and the Trust Territories of the Pacific. The Organic Act, in effect, was modified August 23, 1958, by Public Law 85–743 and again on September 5, 1962, by Public Law 87–626. These laws extend certain authority of the Secretary of the Interior, exercised through the USGS, to areas outside the national domain.

Public Law 80–402, 80th Congress, 2d Session.—United States Information and Educational Exchange Act of 1948:

A government agency, at the request of the Secretary of State, may perform such technical or other services as such agency may be competent to render for the government of another country desirous of obtaining such services *(Section 402)*. Also this law permits the sale of educational and informational material and specialized scientific equipment for dissemination to, or use by, peoples of foreign countries *(Section 801 (2))*.

This law permits the USGS, upon approval of the Department of State, to enter into an agreement with a foreign government for specific services. This requires an exchange of diplomatic notes between the Department of State and the foreign government. The foreign government advances to the Department of State, U.S. dollars to cover the cost of the services to be rendered. These funds are transferred to the USGS where they are utilized to make disbursements.

Public Law 85–743.—Antarctica; Trust Territory of Pacific Islands:

This law of August 23, 1958, modified the Organic Act (43 U.S.C. 31) and provides for the extension of certain authorized functions of the Secretary of the Interior to areas other than the United States, its Territories and possessions. The authority of the Secretary of the Interior to perform surveys, investigations, and research in geology, biology, minerals, and water resources, and mapping was extended to include Antarctica and the Trust Territory of the Pacific Islands.

Public Law 85–795.—Federal Employees International Organization Service Act of 1958:

The law authorizes the USGS to detail or transfer (for a period not in excess of 3 years) an employee to an international organization. A detail may be made without reimbursement, with partial reimbursement, or with full reimbursement to the USGS. The employee on detail continues to receive compensation, allowances, and benefits directly from the USGS, with the international organization reimbursing the USGS, either wholly or partly, as outlined above. However, it also permits the employee to receive directly from the international organization payment or reimbursement for allowances or ex-

penses incurred in the performance of duties required by detail.

Under this law (for details) the USGS does not retain technical supervision of the employee, but he does remain on the rolls of the USGS.

Public Law 87–195.—Foreign Assistance Act of 1961 (AID):

This law, in effect, supersedes Public Law 535 and supplements the Mutual Security Act of 1954 as amended, which governed USGS functions under the aegis of US ICA.

Section 625 (d) (1).—This section authorizes the employment or assignment of personnel to perform functions under the Foreign Assistance Act of 1961 outside of the United States by any agency of the U.S. Government. To perform such functions the USGS enters into a Participating Agency Service Agreement (PASA) with the U.S. Agency for International Development (AID) covering the services to be rendered. A General Agreement under which the participating agency service agreements are executed was signed by the Department of the Interior and the Foreign Operations Administration (FOA) in March 1954, and a new and updated agreement was signed by the Agency for International Development and the Department of the Interior on April 5, 1967. AID supplies funds to cover the cost of each agreement.

Section 607.—This section of the Foreign Assistance Act of 1961 authorizes the U.S. Government agencies to furnish services and commodities on an advance of funds or reimbursement basis to friendly countries, international organizations, the American Red Cross, and voluntary nonprofit agencies registered with and approved by the Advisory Committee on Voluntary Foreign Aid. This section requires a determination by the Administrator of AID that the requested services would be in furtherance of the Foreign Assistance Act of 1961 before the USGS can deal directly with the requesting country or international organization. The USGS retains technical supervision over the employees assigned to the project.

Public Law 87–256.—Mutual Educational and Cultural Exchange Act of 1961:

This public law provides for improvement and strengthening of the international relations of the United States by promoting better mutual understanding among the peoples of the world through educational and cultural exchanges.

Public Law 87–626.—87th Congress, Scientific Examination Authority, Extension:

This law of September 5, 1962, modified the Organic Act (43 U.S.C. 31) of March 3, 1879, and is worded as follows: "Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, that the authority of the Secretary of the Interior, exercised through the Geological Survey of the Department of the Interior, to examine the geological structure, mineral resources, and products of the national domain is hereby expanded to authorize such examinations outside the national domain where determined by the Secretary to be in the national interest."

USGS participation in overseas activities related to the International Hydrological Decade program and to independent investigations and research in extension of domestic research are authorized under Public Law 87–626.

Public Law 91–175.—Foreign Assistance Act of 1969:

This law of December 30, 1969, contains amendments to Public Law 85–795. These include: increase of the allowable period of detail or transfer to an international organization from 3 to 5 years; option by employee to select the retirement system of either his domestic agency or the international agency to which he transfers; and provision for payment on re-employment of differences in pay, allowances, post differential and other monetary benefits that result from the transfer or detail. The detail or transfer also may be extended beyond 5 years under special circumstances where the Secretary of State determines it to be in the national interest.

FUNDING

Historically, the bulk of the U.S. dollar funds required to support USGS overseas personnel assignments, foreign participant training in the United States, purchase of scientific and technical equipment, and related technical and administrative support in the United States have been provided by the US AID and its predecessor agencies. Limited dollar funds, however, have been received directly from foreign governments and from United Nations and regional intergovernmental agencies, chiefly in reimbursement of costs for short-term details to projects and for participant training. Prior to fiscal year 1952 no funds were received directly by the water-resources program of the USGS, as all USGS technical assistance activities were then handled in the USGS Branch of Foreign Geology (now Office of

International Geology). After establishment of the USGS Foreign Hydrology Section (now Office of International Activities) in fiscal year 1952, transferred funds were assigned directly to USGS/OIA.

As shown in figure 1, the USGS overseas water-resources program built up rapidly in the early 1950's but stabilized at an annual level of about $450,000 during the latter half of the decade. A second period of active program growth occurred in 1960–66, but this peaked in 1966 when the funding level reached $1,400,000. Since 1966 the funding has declined to a level of $479,000 in 1971, which is comparable with that of the late 1950's. Over the 21-year term shown in figure 1 the average annual budget has been about $525,000 with a total dollar input of about $11,010,000 to the USGS foreign program in water-resources investigations.

The fluctuations in funding reflect not only the size and scope of the USGS overseas water-resources program but also year-to-year gross variations in U.S. Congressional appropriations for foreign aid and the distribution of these funds among regional bureaus of US AID (fig. 2). The marked decline in funding for fiscal year 1970, however, resulted both from limitations imposed by personnel ceilings, which have inhibited initiation of new overseas projects, as well as from sharp reductions in U.S. foreign aid, which in 1971 was at its lowest level since 1948.

The funds shown in figure 1 represent only the U.S. dollar inputs into USGS international water-resources activities. Indeed, total costs in country projects may be several times greater than the amounts indicated in figure 1. Thus, costs of housing, post allowances, in-country travel, and other miscellaneous expenses are paid directly to USGS overseas water-resources personnel by US AID country missions or other sponsoring agencies, generally in counterpart currencies. Also, vehicles and field support equipment are commonly purchased through channels other than the USGS. Other in-country costs such as office and laboratory space and equipment and salaries of host-country support personnel also are not reflected in USGS dollar budgets.

Funds allocated to the USGS for participation in the program of the International Hydrological Decade are not included in figure 1. An expanded program for USGS water-resources participation in the IHD was included in fiscal year 1967, 1968, 1969, and 1970 budget presentations of the USGS but has continued to be approved by the Congress at approximately the same annual level. The funds allocated

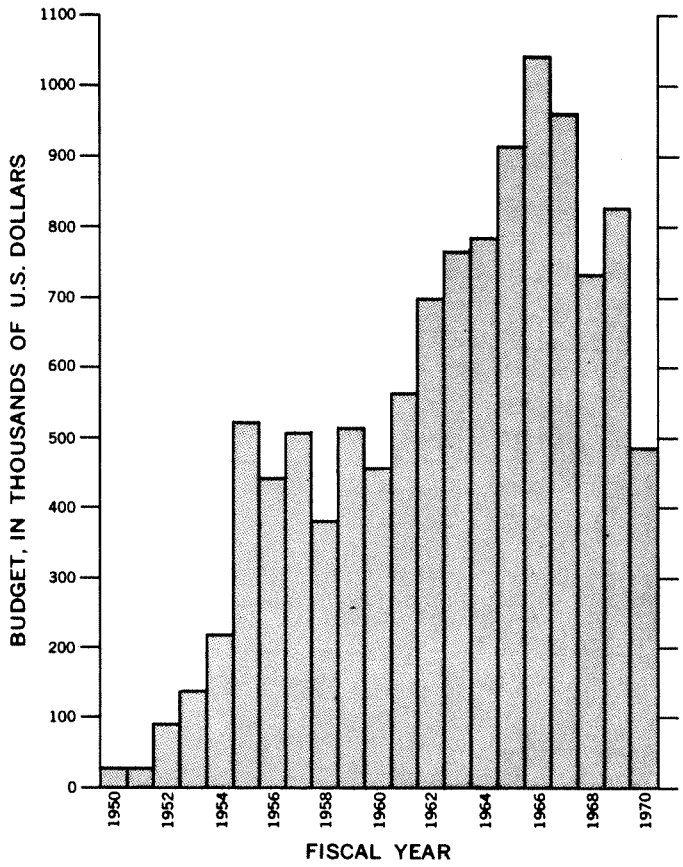

FIGURE 1.—Distribution of USGS water-resources foreign program funds by fiscal years, 1950–70.

to USGS for the IHD program by fiscal years since 1965 are as follows:

1965	$2,500	1969	$153,500
1966	$178,000	1970	$158,400
1967	$150,000	1971	$170,400
1968	$150,000		

The bulk of these funds have been expended for USGS domestic water-resources projects identified with the objectives of the IHD. A part of the funds, however, have been used for international travel related to technical support of UNESCO/IHD Secretariat activities and of the participating country programs.

As a result of the U.S. balance of payments deficits and the increasing will of many developing countries to "pay their own way," there has been an increase since about 1965 in the projects being conducted by the USGS which are financed from funds advanced by the host governments. Thus far such projects, except for the USGS minerals investigations program in Saudi Arabia, have been of short duration (for example, Kuwait, 1 month; Libya, 1 month; Argentina, 1 month; Chile, 6 months; Vene-

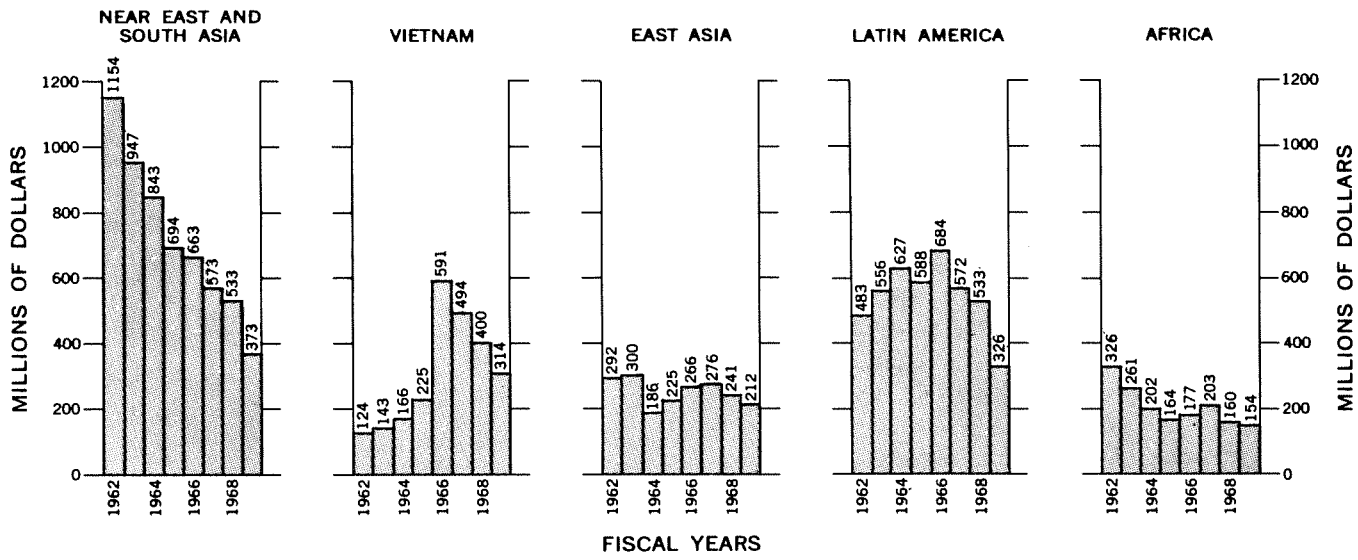

FIGURE 2.—Distribution of aid, in millions of dollars, among regional bureaus of the U.S. Agency for International Development during 1962–69. (From US AID "Front Lines.")

zuela, 1 month). It is expected, however, that such projects may increase as AID grant and loan projects are reduced.

HEADQUARTERS TECHNICAL AND ADMINISTRATIVE SUPPORT

The Office of International Activities for the USGS water-resources program had as its chief functions in 1971 the direction, guidance, and logistic support of USGS water-resources country projects under the U.S. bilateral program and foreign participant training in the United States. Beginning as a one-man effort in 1952, the OIA, formerly Foreign Hydrology Section, has since grown to a staff of two professionals, a foreign participant assistant, a cartographic technician, two secretaries, and a part-time editorial clerk.

The OIA has served as a connecting link between the domestic and overseas water-resources programs of the USGS; scheduled the bulk of the intern training as well as the study programs of visiting foreign water scientists and engineers in the USGS domestic water-resources offices; designed, negotiated, and implemented new country projects and provides technical backstopping to USGS water-resources personnel in active projects of the U.S. bilateral program; assisted from time to time in the identification and scheduling of appropriate USGS water-resources personnel for assignments to projects of the United Nations and regional intergovernmental agencies; regularly provided technical logistic support in the USA in the procurement of hydrologic equipment and supplies for overseas USGS water-resources projects and from time to time projects of foreign governments and UN agencies; reviewed and processed technical and administrative reports resulting from USGS country projects in water resources; and occasionally scheduled field reviews by USGS headquarters personnel of country projects. Prior to 1971 the OIA had not been directly involved with USGS participation in activities related to nongovernmental organizations, with hydrologic investigations abroad in extension of domestic research, nor with the UNESCO/IHD program.

Since 1965 the Chief Hydrologist's staff in the USGS under the direction of R. L. Nace has provided guidance and technical backstopping for domestic and overseas activities of the IHD.

REPORTS AND PUBLICATIONS

The diversity of USGS overseas water-resources activities results in a variety of reporting requirements. Technical and scientific reporting on water-resources investigations has not always been of priority concern in in-country projects of the U.S. bilateral program, but has been an important secondary product resulting from the primary objective of institutional development. Such reporting is, however, frequently paramount in respect of participation by USGS personnel in water-oriented international conferences, symposia, seminars, and workshops sponsored by United Nations and regional inter-governmental agencies, nongovernmental international organizations, and USGS water-resources investigations and research abroad in extension of domestic research.

Administrative reporting has been a dominant requirement for intra-agency as well as inter-agency communication in all overseas projects in the U.S. bilateral program and, indeed, has high priority in most multilateral agency activities. Such administrative reports include, among others, proposals for design and content of new projects, progress reports, project review and evaluation reports, individual end-of-tour reports, and reports recounting the history and results of completed projects.

Most reports in the administrative category are considered internal operational documents and are not available to the general public. Technical and scientific reports, however, are generally available to the public and include formal publications and open-file reports of the U.S. Geological Survey; articles published in technical and scientific journals, both in the United States and abroad; and formal publications and open-file reports of foreign governmental and international agencies. Between 1940 and 1970, for example, some 336 technical and scientific reports resulted from overseas water-resources projects in the U.S. bilateral program and were made available to the public.

Formal publications and open-file reports of the USGS and of foreign governmental agencies that have resulted from USGS water-resources projects in the U.S. bilateral program are listed with country descriptions in this report. References relating to USGS participation in water-resources projects of the United Nations and regional intergovernmental agencies, in the UNESCO/IHD program, governmental scientific and technical exchange and cooperation, nongovernmental international scientific organizations, and investigations and research abroad in extension of domestic research are not generally listed in this report.

FOREIGN PARTICIPANT EDUCATION AND TRAINING

During the past 30 years, well-trained and experienced scientists, engineers, and technicians have generally been in short supply in the developing countries; consequently, education and training of personnel is essential in any effort to help these countries attain higher levels of economic and social viability. As the principal agency in the U.S. Government concerned with geologic, hydrologic, and cartographic surveys and research, the USGS has accepted responsibility to help train scientific and technical personnel and encourage the growth of agencies with comparable functions in the developing countries. During the past three decades the USGS has provided or arranged for the training and education in the United States for some 1,100 participants from 79 countries in geology, geophysics, geochemistry, hydrology, hydrogeology, cartography, scientific and technical publication, administration, and related fields. The bulk (perhaps 90 percent) of the participant training has been sponsored and financed by the U.S. Agency for International Development or its predecessor agencies. The USGS, however, has also provided training for a substantial number of participants sponsored by agencies of the UN family as well as regional intergovernmental agencies and also by direct government-to-government arrangements through the U.S. Department of State.

USGS assistance in the education and training of foreign nationals has been carried out in three ways: (1) on-the-job training under the guidance of USGS specialists assigned to technical assistance projects in other countries, (2) in-service (intern) training of individual participants assigned to headquarters, field projects, or laboratories in the USGS domestic program, and (3) guidance or assistance by the USGS foreign participant program staff in selecting appropriate curricula and universities for academic studies in science and engineering by participants. Depending on the needs of the participant, individual programs have been designed either for intern training or for academic studies; however, many programs in recent years have been combinations of both. Also, intern training available at USGS domestic facilities has been commonly coordinated or augmented with training at other U.S. Federal agency facilities and from time to time with private companies, so as to give the participant a spectrum appropriate to his individual needs.

The USGS has been involved in foreign participant training in the water sciences and engineering since the early 1940's, but the level of activity was relatively low during the 1940's and early 1950's. Beginning in 1956, however, activity sharply increased to a high in 1962. The total level in 1971, however, promises to exceed that of 1962. The number of participants trained per year during 1956–70 ranged from 26 in 1956 to 57 in 1962. The average number trained during the 1960's was 47 per year at a relatively constant rate.

Table 1 shows the numbers of foreign participants provided intern and academic training and education programs through USGS domestic water-resources facilities and their countries of origin for 1950–70. As of the end of 1970 and since 1940 the USGS has provided training in the United States for 428 for-

TABLE 1.—*Countries for which participant education and training has been provided in the United States through USGS domestic water-resources facilities with numbers of participants from each country, 1950–70*

North and South America		Europe		Africa		Asia	
Argentina	6	France	1	Congo (Kinshasa)	4	Afghanistan	13
Bolivia	2	Germany	1	Egypt (UAR)	17	Burma	1
Brazil	37	Great Britain	1	Ethiopia	3	Ceylon	1
Canada	1	Greece	7	Ghana	3	India	29
Chile	15	Iceland	2	Kenya	2	Indonesia	7
Colombia	3	Poland	2	Liberia	1	Iran	5
Costa Rica	2	Spain	5	Sudan	11	Iraq	4
Cuba	1	Yugoslavia	2	Tanzania	1	Israel	9
Guatemala	1	Total	21	Togo	1	Japan	7
Guyana	5			Uganda	1	Jordan	19
Haiti	2			Union of South Africa	1	Korea	8
Jamaica	2			Total	45	Lebanon	1
Mexico	3					Libya	4
Panamá	1	Australia	1			Nepal	16
Peru	2					Pakistan	46
St. Lucia, W.I.	1					Philippines	28
Uruguay	1					China (Taiwan)	16
Venezuela	8					Saudi Arabia	1
Total	93					Syria	1
						Thailand	13
						Turkey	38
						Vietnam	1
						Total	268

mally scheduled and funded participants from 60 different countries. The duration of individual programs ranged from a few days to as much as a year, but most of the programs were in the range of 2 to 6 months. In addition, informal scientific and technical consultation has been provided by USGS water-resources specialists in the United States to an even greater number of unscheduled or casual foreign visitors. It is interesting to note from table 1 that the countries providing the largest number of participants correspond to those where the USGS has had intensive involvements in water-resources projects in the U.S. bilateral technical assistance program—notably Brazil and Chile in Latin America; Egypt and Sudan in Africa; and Afghanistan, India, Jordan, Nepal, Pakistan, Philippines, Thailand, and Turkey in Asia.

Most in-service training in USGS water-resources facilities during the past 30 years has been directed to the scientific and technical requirements of foreign geologists, engineers, chemists, and professionals in various aspects of the basic disciplines of general hydrology, surface-water hydrology, groundwater hydrology, and hydrochemistry. From time to time, however, training has been provided for participants of supervisory grade in administration, management, programing and planning techniques necessary to the operation of water-resources and hydrological organizations that function at national, regional, or provincial levels. The USGS has also provided group training in hydrology for foreign participants on several occasions during the past 10 years, chiefly through its Water Resources Training Course in Denver, Colo.

PROCUREMENT OF HYDROLOGIC EQUIPMENT FOR OVERSEAS PROJECTS

One of the more important functions of the OIA is provision of technical logistic support in the USA for procurement of special hydrological equipment and related supplies needed in overseas USGS water-resources projects and occasionally in hydrological investigations projects of foreign governments and UN agencies. OIA, however, does not normally become involved in common commodity procurement, which is regularly handled by the General Services Administration (GSA).

The bulk of the funds for hydrological equipment purchases in USA have been provided to OIA from US AID and its predecessor agencies. Some dollar credits, however, also have been received from UN agencies and from foreign governments for purchases of hydrological equipment. During the years 1964–69, hydrological equipment purchases for US AID-sponsored projects averaged about $70,000 per year with a peak of about $100,000 in 1966. The distribution of dollar amounts for hydrological equipment purchases for individual country projects during this 5-year period is shown below:

Brazil	$133,000	Egypt	$38,420
Afghanistan	82,880	Ethiopia	12,020
Nigeria	53,040	Jordan	10,100
Thailand (Mekong Committee)	40,000	Kenya	4,300

In addition intermittent purchases of hydrologic equipment for foreign governments and UN agencies has been in the range of about $5,000 to $10,000 a year.

INTERNATIONAL ACTIVITIES

From the foregoing discussions it is evident that the USGS activities in other countries do not constitute and cannot be a tightly integrated program, owing to the diversity of requirements of the sponsoring agencies, through which the USGS must operate. These activities can be grouped, however, in five general categories as follows: bilateral activities, multilateral activities, governmental scientific and technical exchange and cooperation, cooperation with nongovernmental international organizations, and investigations and research abroad in extension of domestic projects. Among these categories, technical assistance under the U.S. bilateral program and related foreign participant training constituted as of 1971 the bulk of USGS water-oriented overseas activity. During the past 10 years, however, there has been a marked increase in the level of USGS water-resources activity with multilateral agencies and nongovernmental international organizations. In other categories listed above, USGS water-resources activity also has been highly significant, scientifically and technically, but not large in terms of funding or intensity of involvement. USGS international water-resources activities during 1940–70 in these five categories in various countries and with various sponsoring agencies are described in the following sections but with larger emphasis on projects in the U.S. bilateral program.

BILATERAL ACTIVITIES

Most USGS long-term overseas water-resources projects and individual assignments prior to 1970 can be grouped in the U.S. bilateral program, sponsored by US AID and its predecessors and also by direct arrangements through the U.S. Department of State with foreign governments. USGS international water-resources activities in this category are authorized under terms of Public Laws 80–402 and 87–195.

Between 1940 and 1970, some 253 individual assignments, ranging from a few days to several years duration, were completed on short- and long-term projects in 46 countries (table 2) in bilateral activities. Regionally, the bulk of USGS water-resources activity in the U.S. bilateral program has been concentrated in the countries of the Near East and South Asia, where high priority has been given during the past 20 years to water-resources development and related institutional building. Generally, a somewhat lower level of activity has prevailed in Africa—with the notable exceptions of the United Arab Republic (Egypt), Libya, and Nigeria. In Latin America, USGS water-resources activities in bilateral assistance have been concentrated very largely in Brazil and somewhat less in Chile (table 2). USGS water-resources participation in bilateral activities in various regions of the world and in individual countries is described in the following sections.

TABLE 2.—*Countries to which the USGS water resources personnel have been assigned under U.S. bilateral assistance with numbers of assignments, and years during which projects were active in each country, 1940–70*

Latin America	Europe
Argentina, 3—1959; 1962	Belgium, 1—1960–62
Bahama Islands, 5—1953; 1954–55	Greece, 2—1948–50; 1966
Brazil, 26—1953; 1960; [1] 1961–75	Netherlands, 1—1958–59
Costa Rica, 1—1964	Portugal (Azores), 1—1950
Chile, 8—1945–48; 1950; 1955–62; 1969; 1970	Total number of assignments ------- 5
El Salvador, 2—1943–44	
Guyana, 1—1957	
Haiti, 2—1948–49; 1959	
Nicaragua, 3—1943; 1956	
Panamá, 4—1949; 1962; 1964–65	
Peru, 1—1955–59	
Total number of assignments ------ 56	

Africa	Asia
Chad, 1—1962	Afghanistan, 10—1952–69; [1]1971
Congo (Kinshasa), 1—1968	Cambodia, 3—1958; 1959; 1963
Egypt, 26—1953–56; 1959–67	India, 10—1950; 1951–57; 1966; 1968; 1970; [1]1971–74
Ethiopia, 4—1966; [1]1968–73	Iran, 6—1952; 1953–63; 1968
Ghana, 1—1964	Iraq, 1—1958
Kenya, 5—1967; [1]1968–75	Israel, 1—1962
Libya, 13—1952–64; 1967; 1969; 1970	Japan, 2—1951; 1964
Nigeria, 14—1961; 1962–1968	Jordan, 4—1958; 1959–60; 1962; 1966
Rhodesia, 1—1959	Korea, 5—1963; 1964; 1965; 1966–71
Senegal, 1—1965	Kuwait, 2—1947; 1965
Sudan, 2—1955; 1961–63	Nepal, 9—1961; [1]1962–74
Tunisia, 3—1958; 1959–65	Pakistan, 27—[1]1953–71
Zambia, 1—1968–1970	Philippines, 5—1955; 1957–61; 1967
Total number of assignments ---- 73	Saudi Arabia, 2—1945–46; 1952–53
Australia, 7—1963; 1966; 1967; 1969	Thailand, 8—1954; 1961; 1970
	Turkey, 8—1957; 1958–62; 1963–65; 1966; 1967
	Vietnam, 9—1964–66; 1968–70
	Total number of assignments --- 112

[1] For currently (1970) active projects final year indicated is that of planned project termination.

LATIN AMERICA

Although the USGS has a record of participation in water-resources projects of bilateral assistance in Latin America (fig. 3) that dates back before the beginning of this century, the overall level of involvement, regionally, has been somewhat less than in Africa and only about half that in Asia (table 2). Nevertheless, projects have been undertaken and completed in 12 Latin American countries since 1940 through 63 individual assignments, among which the preponderance have been in Brazil, virtually all since 1960.

FIGURE 3.—Index map of Latin America showing those countries (shaded) in which the U.S. Geological Survey has been active in water-resources projects of the U.S. bilateral assistance, 1940–70.

ARGENTINA

Argentina, land of the vast and fertile pampa, the gaucho, and some of the world's finest beef cattle, lies in southern South America and is the second largest country on the continent. Beginning its early history as a Spanish colony, Argentina gained its independence in 1816 under the leadership of General José de San Martín, the national hero. Despite its impressive human and natural resources, Argentina has experienced considerable political turbulence and economic difficulty since World War II. The United States, as one of Argentina's principle trading partners and in the interest of strengthening the economy, provided some $157 million in bilateral economic aid and technical assistance between 1957 and 1968. The USGS participated briefly in the water-resources sector of the bilateral program first in 1959 and again in 1962.

As a result of a request in early 1959 from the Argentine Dirección Nacional de Geología y Minería (DNGM) to US ICA/Buenos Aires, S. L. Schoff, USGS hydrogeologist, was assigned for a 3-month tour (July–October 1959) to evaluate the national ground-water investigations program of DNGM's Hydrogeologic Service and to recommend ways and means of improving collection and recording of data; observation well networks; areal geologic and hydrologic studies; hydraulic, geochemical and chemical studies; technical reporting; and hydrologic and geologic equipment. His report of April 1960 evaluated these needs and presented recommendations for their fulfillment. Also during his tour Mr. Schoff participated with Argentina hydrogeologists of the DNGM in reconnaissance areal ground-water studies in the Pampa del Castillo and Cañadón de El Trebol, 40 to 60 km (kilometres) west of Comodoro Rivadavia; in the Bahía Blanca area; and in the Santa María Valley, Provincia de Catamarca of northwestern Argentina. The results of these studies were released in three open-file or published reports.

For several years, ground-water users in the La Plata area along the southern margin of the Rio de La Plata estuary had been coping with declining water levels in supply wells and concurrent deterioration in chemical quality, owing to salt-water encroachment. Early in 1962 the Laboratorio de Ensayo de Materiales e Investigaciónes Tecnológicas (LEMIT) through the Buenos Aires Provincial Comision de Investigaciónes Científicas (CIC) at La Plata requested assistance from US AID/Buenos Aires for the short-term services of a U.S. specialist to formulate a ground-water program in this area. W. W. Doyel, USGS hydrogeologist, was assigned to work with LEMIT for a 6-weeks tour (July–August 1962). Based on recommendations in Mr. Doyel's administrative report of August 1962, a 4-year project designated "Ground Water in the Northeast of Buenos Aires Province" was begun in February 1966 and has since been carried to a successful conclusion. The findings of this investigation, involving the services of 10 full-time LEMIT geologists, engineers and technicians, provide a base for planning the rational utilization and management of the ground-water resources in a 20,000-km^2 (square kilometre) area in the commercial and industrial heartland of Argentina.

Between 1962 and 1971, the USGS also provided short-term specialists on several occasions, both in surface-water and ground-water investigations, to United Nations and Organization of American States (OAS) projects in Argentina. These activities are described under "Multilateral Activities."

References

Arnow, Ted, 1971, Reconnaissance of dam and reservoir sites in the Upper Río Bermejo Basin, Argentina: U.S. Geol. Survey open-file rept., 78 p., 11 figs.

Porterfield, George, 1972, Reconnaissance of sedimentation in the Upper Río Bermejo Basin, Argentina: U.S. Geol. Survey open-file rept., 110 p., 17 figs.

Schoff, S. L., 1959a, Ground-water reconnaissance of Santa Maria Valley, northwest Argentina: U.S. Geol. Survey open-file rept., 14 p.

——— 1959b, Observations on the ground water of El Trebol and the Pampa del Castillo, near Comodoro Rivadavia, Provincia de Chubut, Argentina: U.S. Geol. Survey open-file rept., 6 p.

——— 1964, Salso, Jorge H., and Garcia, José, Source of heat in a deep artesian aquifer, Bahía Blanca, Argentina *in* Geological Survey research 1964: U.S. Geol. Survey Prof. Paper 501–D, p. D153–D157.

BAHAMA ISLANDS

The archipelago of the Bahamas, containing 700 low-lying islands and 2,000 rocks and keys, stretches 800 kilometres southeastward from Florida. From its former status as a British colony, the Bahamas became a self-governing commonwealth in January 1964. Since World War II the U.S. has maintained several installations in the islands for which the USGS has provided technical consultation in water-supply problems. These activities are described below.

Before 1953 the U.S. Air Force had depended almost entirely on paved rainfall-catchments to supply fresh-water requirements for its installations on the islands of Grand Bahama, Eleuthra, San Salvador,

Mayaguana, and Grand Turk in the Bahama Group. Owing to increasing demands for water at these installations, the U.S. Air Force in early 1953 requested the USGS to study fresh ground-water bodies on these islands with a view to determining their adequacy for supplementing supplies from the catchments.

In a first preliminary study of San Salvador and Mayaguana in August 1953, N. D. Hoy, USGS hydrogeologist, obtained basic data on existing ground-water supplies and selected areas for development of additional supplies. M. C. Schroeder, USGS hydrologist, made a second reconnaissance in December 1953 and directed drilling of shallow test holes on San Salvador and Mayaguana to determine permeabilities of the water-bearing coralline sand and limestone and ground-water quality near existing supply wells. A third reconnaissance was made by N. D. Hoy and Howard Klein in January 1954 of all five islands to determine ground-water quality near U.S. Air Force installations, to choose areas likely to yield fresh ground-water supplies and to select sites for exploratory drilling. Between July 1954 and April 1955, 91 exploratory wells were put down on the 5 islands for water and formation sampling and aquifer testing.

The fresh ground-water lenses on the islands generally range from 2 to 7 m (metres) thick, but on Grand Bahama, which has a relatively high rainfall, the lens is 15 m or more thick. Also the fresh-water lenses expand and contract seasonally with the flux of recharge from rainfall and subsequent dissipation of head by discharge. In their report of January 1958, Messrs. Klein, Hoy, and Sherwood recommended development of the fresh-water lenses by skimming from shallow wells with a rigorous program of water-level and salinity observations to avoid overpumping and resultant salt-water contamination.

Reference

Klein, Howard, Hoy, N. D., and Sherwood, C. B., 1958, Geology and ground-water resources in the vicinity of the Auxiliary Air Force Bases, British West Indies: U.S. Geol. Survey open-file rept., 142 p., 49 figs.

BRAZIL

Although Brazil has abundant natural resources, it has had to face tremendous social and economic problems in attempting to find, evaluate, and develop these resources. In recent years, considerable progress has been made in solving these social and economic problems, and Brazil's efforts to explore and develop its resources have greatly increased. The USGS has been privileged to cooperate with Brazilian resources agencies in these efforts, as part of the U.S. assistance program in Brazil. USGS technical assistance in mineral and geological investigations with Brazilian agencies has been continuous since the early 1940's. USGS participation in the water-resources sector of the U.S. bilateral program in Brazil is more recent, first in 1953, again in 1960 and then continuously between 1961 and 1971. The scope and nature of this work are described in following sections.

Possibly the earliest recorded USGS work on water-resources investigations in Brazil resulted from a request in 1910 to the U.S. Department of State from the Government of Brazil for advisory assistance in the establishment of a ground-water investigations section in the National Department of Mineral Production (DNPM). G. A. Waring, USGS hydrogeologist, was assigned to the work and, beginning in September 1910, spent several weeks in field reconnaissance in northeast Brazil and in office consultations in Rio de Janeiro, during which time he formulated a proposed program for DNPM. This program apparently was never implemented owing to lack of funds and organizational direction.

Dewatering and Mine Drainage in Open-Cast Mining of Phosphate Deposits at Olinda near Recife, Pernambuco, 1953

The first USGS involvement in areal water-resources studies in Brazil was a short-term investigation of ground-water problems related to the development of the phosphate deposits at Olinda, near Recife in the State of Pernambuco. This study sponsored by the US TCA at the request of the National Department of Mineral Production (DNPM) was made by G. A. Rynearson and E. W. Reed of the USGS during April and May 1953. The study included a detailed description of the stratigraphic and mineralogic characteristics of the phosphate deposits and an analysis of the dewatering and mine-drainage problems that would be related to open-cast mining of the deposits.

Appraisal of the Status of Ground Water Investigations and Development in Brazil, 1960

The first appraisal of the status of investigations and development of Brazil's ground-water resources was made for US ICA by Robert Schneider, USGS hydrogeologist, in early 1960. During his 3-month stay (February–May 1960) in Brazil, Mr. Schneider interviewed key officials in Federal, State, and local governmental agencies as well as private companies and individuals with interest or concern in ground-

water problems. Among those Federal agencies contacted were the Serviço Especial de Saúde Pública (SESP), the Departamento Nacional de Produção Mineral (DNPM), the Departamento Nacional de Obras Contra as Sêcas (DNOCS), the Departamento Nacional de Obras de Saneamento (DNOS), the Comissão do Vale do São Francisco (CVSF), and the Superintendência do Desenvolvimento do Nordeste (SUDENE). All these agencies have some degree of involvement in ground-water investigation and development.

Mr. Schneider also identified the larger ground-water provinces of Brazil and their general development potential for irrigation, public, industrial, and rural water supply. In his report of June 1960, he pointed out the particular need for systematic ground-water investigations coupled with development in northeast Brazil, in the São Paulo industrial area, of alluvial aquifers in the large river valleys and of general hydrologic networks for collection of essential basic data.

Hydrogeologic Education and Training in the CAGE Project, 1961–64, and Hydrogeologic Reconnaissance of Northeast Brazil, 1962

During July 1961 to January 1964, D. J. Cederstrom, USGS hydrogeologist, was assigned to the CAGE (Campanha para a Formacão de Geologos or Geologic Training Campaign) educational project sponsored by DNPM under US AID auspices to introduce the study of ground-water geology and hydrology in Brazil on a formal basis. Classes in these topics were held in the DNPM headquarters building in Rio de Janeiro, along with other classes in several other fields of geology. The first school year, three lectures a week were given to a class of seniors. In the following school year one course for 21 seniors was held, and in the next school year a course for junior and another for senior students was given. Enrollment averaged about 17 students in each class. Lectures were given in Portuguese.

In the latter part of the second year, the continuity of the courses was interrupted, when Mr. Cederstrom suffered an accidental fracture of his hip. During his convalescence he prepared a general text, "Agua Subterrânea," in the Portuguese language that was later published by US AID/Rio de Janeiro. This text has since received wide circulation in university and government circles throughout Brazil and elsewhere in Latin America as a basic reference on ground-water geology and hydrology.

In January–February 1962, Mr. Cederstrom made an 8,700-km reconnaissance of northeast Brazil to observe geohydrologic conditions and related socio-economic problems in the Drought Polygon of northeast Brazil. In his report of June 1962, Mr. Cederstrom pointed out the development potential of ground water in the alluvial deposits of the larger stream valleys; the possible uses of rainwater catchments (cisterns) for domestic water supply in rural areas; and the needs for continuing maintenance and proper management of earthen surface-water impoundments (açudes) and drilled wells constructed by DNOCS and SUDENE. He also suggested ways of improving the prevailing poor chemical quality of the native ground water by in-tandem use of dug wells, cisterns, and spreader dikes. Mr. Cederstrom's recommendations were subsequently included in ground-water investigations in northeast Brazil as described in the following section of this report.

Water Resources Investigations in Northeast Brazil, 1962, 1963–68

Water-resources investigations with USGS participation were begun in June 1962 in the Drought Polygon of northeast Brazil and adjacent areas, as part of a general US AID-sponsored development program. US AID/Recife provided administrative backstopping throughout the life of the program. As elsewhere, water-resources investigations in this region are essential for planning, development, and management of water resources for rural, municipal, and industrial water supply and for irrigation and hydropower. The chief counterpart agency for the USGS team during the life of the program was the Natural Resources Department of the Superintendency for the Development of the Northeast (SUDENE). Close contact, however, was maintained with the National Drought Relief Department (DNOCS); the National Department of Sanitary Works (DNOS); the National Department of Mineral Production (DNPM); and the Commission for the San Francisco Valley (CVSF), as these agencies are also involved in water-resources development and management in the Northeast.

As identified by US AID/Recife, the water-resources program included two components, (1) hydrologic data collection and analysis on streams of northeast Brazil (surface-water investigations), and (2) exploration of ground-water resources for improved land use in the Drought Polygon (ground-water investigations). Financed by US AID grant funds, the program was continued over a 5-year term and phased out in November 1968.

Surface-water investigations.—U.S. Geological Survey technical support of surface-water investigations in northeast Brazil began in January 1963 with

the arrival in Recife of L. J. Snell, USGS hydrologist, who was assigned as project chief and advisor to the Hydrology Division, Natural Resources Department of SUDENE. The general objectives of the hydrologic investigations included: (1) expansion and improvement of the field network of streamflow, rainfall, and evaporation stations, (2) field and office training of SUDENE hydrologists, (3) annual compilation and publication of hydrological data, (4) computation, evaluation, and publication of a backlog of 30,000 station years of rainfall and 1,700 of streamflow data. From March 1964 to March 1966, the late R. O. R. Martin, USGS hydrologist, was assigned to the project to guide the work of computation and evaluation of rainfall and streamflow data; he was assisted in this work for 3 months in early 1965 by G. E. Philipsen, also a USGS hydrologist.

Mr. Snell concentrated his efforts in guiding the overall direction of the project, in assisting SUDENE to form an effective organization for collection of hydrological data, in working out operating methods and procedures to be used by SUDENE and in training SUDENE hydrologists. Mr. Snell returned to the USGS domestic program in October 1965.

In August 1966, W. F. Curtis, USGS hydrologist, was assigned to the project to continue the work of Mr. Snell in advising SUDENE on technical problems related to hydrologic-data collection, in working out operational procedures to be used by SUDENE, and in training personnel. Mr. Curtis also oversaw the final stages of publication by SUDENE of the rainfall and streamflow data compilation, which had been brought near completion by Mr. Martin. USGS technical support of SUDENE's program of surface-water investigations ended in December 1967, when Mr. Curtis was transferred from Recife to Rio de Janeiro. At this time the SUDENE Division of Hydrology was functioning well in the field collection of basic hydrologic data. A network had been established of 120 operating streamflow measuring stations in northeast Brazil. The network had 31 stations equipped with modern continuous water-stage recorders, 1,930 rain gages, 78 maximum and minimum temperature stations, and 37 evaporation stations. Staff and facilities for computation and publication of streamflow records were still, however, inadequate. In addition, 40 hydrologic technicians and engineers had been given individual and group training in the basic field and office methods and observational techniques of surface-water hydrology.

As of March 1970, 60 streamflow stations out of 120 were considered to have excellent records that were being computed and compiled on an annual basis. Also efforts were being made to improve records at the remaining 60 stations through better definition of stage-discharge relationships.

Ground-water investigations.—The technical base of USGS support of ground-water investigations in northeast Brazil was established by S. L. Schoff, USGS hydrogeologist, in a 3-month reconnaissance in mid-1962. His report of October, 1962 evaluates in considerable depth the needed scope of ground-water investigations in northeast Brazil, including types of investigation, organizational needs, staffing, equipment, and reporting. The long-term project was implemented in June 1963 with the arrival of Mr. Schoff in Recife as project chief and advisor to the Hydrogeology Division, Natural Resources Department of SUDENE. In December 1963 and June 1964, respectively, W. C. Sinclair and H. G. Rodis, both USGS hydrogeologists, were assigned to the project. Mr. Rodis remained until August 1966 and was not replaced owing to curtailment of funds. Mr. Schoff returned to the U.S.A. in September 1967. Mr. Sinclair, however, stayed on in northeast Brazil until November 1968, when he returned to the U.S.A. and reassignment in the USGS domestic program. The objectives of the project were (1) to train SUDENE hydrogeologists in methods and techniques of areal ground-water investigations and (2) to carry out actual field investigations of representative or critical areas as demonstration projects.

Mr. Schoff directed his efforts toward group training of the SUDENE hydrogeology staff, in preparing Portuguese language training materials in hydrogeology, in general liaison between US AID/Recife and SUDENE's ground-water program, and in special studies of ground-water salinity in the Upper Paraíba basin, the results of which were published in USGS Water-Supply Paper 1663–H.

Messrs. Sinclair and Rodis concentrated their efforts in individual field training of SUDENE hydrogeologists and personal participation in ground-water investigations in the Upper Capibaribe Basin, the Açu Valley, the Teresina-Campo Maior area, and the Irece area of the Northeast. The technical results of the first three investigations were published in USGS Water-Supply Papers 1663–E, 1663–C, and 1663–G, respectively.

By the time the USGS support was terminated in December 1968, the USGS hydrogeology team had actively participated in and completed ground-water investigations of some six areas of the Northeast

and had advised, intermittently, SUDENE hydrogeologists working in several other areas. Also, the Hydrogeology Division staff had been increased from 3 to 24 professional hydrogeologists, most of whom had been trained to competence by the USGS team.

Overall, both the surface-water and ground-water segments of the USGS-supported water-resources program in northeast Brazil achieved perhaps 80 percent of original objectives in water-resources investigations and institutional development. Both the Hydrology and Hydrogeology Divisions of SUDENE were functioning organizations in 1970 with competent staffs of hydrologists and hydrogeologists, most of whom are personally interested in increasing their knowledge and capability. Also the USGS has continued, since 1968, active participant training programs for young Brazilian hydrogeologists and hydrologists newly recruited to SUDENE.

Hydrologic Investigations in the Araguaia-Tocantins River Basin, 1964, 1965

At the request of the Interstate Commission for the Araguaia-Tocantins Valley (CIVAT) to US AID/Recife, L. J. Snell, USGS hydrologist, was assigned in June 1964 to review hydrologic-data activities in the Araguaia-Tocantins River Basin which covers 770,000 km^2 in east-central Brazil and to recommend a program to meet the needs for feasibility studies of proposed large-scale developments for hydroelectric power, navigation improvements, and drainage and for industrial and municipal water requirements. Mr. Snell's report of June 1964 described the streamflow (fig. 4) characteristics at seven gaging stations on the Tocantins and Araguaia Rivers, for which records beginning in 1961 were available, and he suggested locations and instrumentation needs for 33 primary additional stations as well as requirements for precipitation and evaporation stations in the basin.

In April 1966, Mr. Snell's recommendations were incorporated, with some additions and modifications by F. F. LeFever, USGS hydrologist, in a report outlining the needs for implementation of geologic mapping, mineral resources evaluation, topographic mapping, basic geodetic control, and hydrologic investigations in the CIVAT region.

Amazon River Investigations, 1963–69

When the International Association for Scientific Hydrology (IASH) began, in 1957, a program for assessment of river-borne dissolved solids from all sources carried to the oceans, the investigators found little published information on the Amazon River. This situation led in May 1961 to a joint proposal by

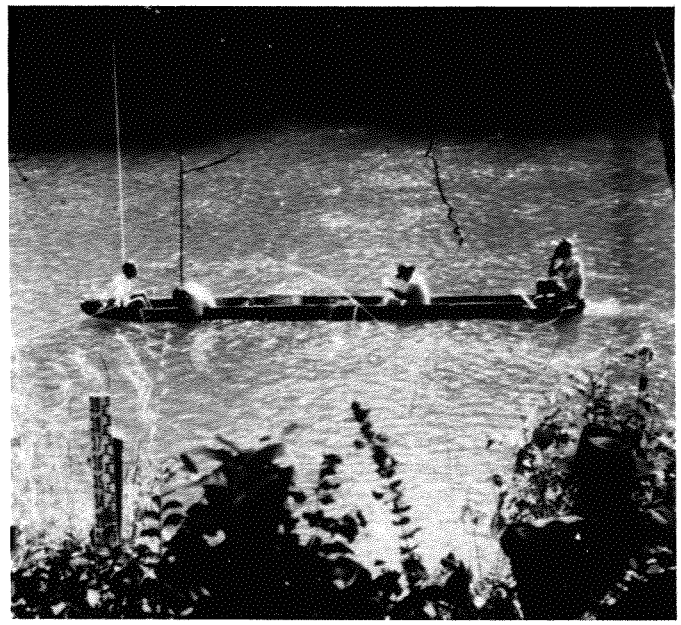

FIGURE 4.—Brazilian engineers measuring flow of the Rio Araguaia near Alto Araguaia with guidance from L. J. Snell, USGS hydrologist. Staff gage for measurement of river stage in foreground.

L. B. Leopold, Chief Hydrologist of the USGS, W. B. Langbein, USGS Staff Scientist, and Professor H. O'R. Sternberg, Director of the Brazilian Center for Geographic Research at the University of Brazil, for measuring the flow, solute load, and sediment concentration of the Amazon River. Professor Sternberg gained the backing of Vice Admiral Helio Garneir Sampâio, Director of Hydrography and Navigation, Brazilian Ministry of the Navy, who agreed to provide a suitable gaging vessel, while, at the same time the USGS agreed to provide an expert hydrologic team (fig. 5), and equipment.

R. E. Oltman, as team leader, and F. C. Ames, L. C. Davis, and G. R. Staeffler were designated as the USGS hydrologic team to carry out the work. They were ably assisted by several Brazilian naval officers, by Professor Sternberg, and by L. J. Snell, also a USGS hydrologist. In all, three hydrologic reconnaissance expeditions were completed by the USGS team in July 1963, October–November 1963, and August 1964 at high, low, and medium river stage, respectively. The measurements (fig. 6) of 1963–64, plus antecedent stage records, indicate well-supported mean annual water discharge of the Amazon River at Óbidos of 157,000 m^3/s (cubic metres per second). The Amazon River is indeed the largest river in the world with more than 10 times the average flow of the Mississippi. Another fact of interest is the surprising purity of the water of the

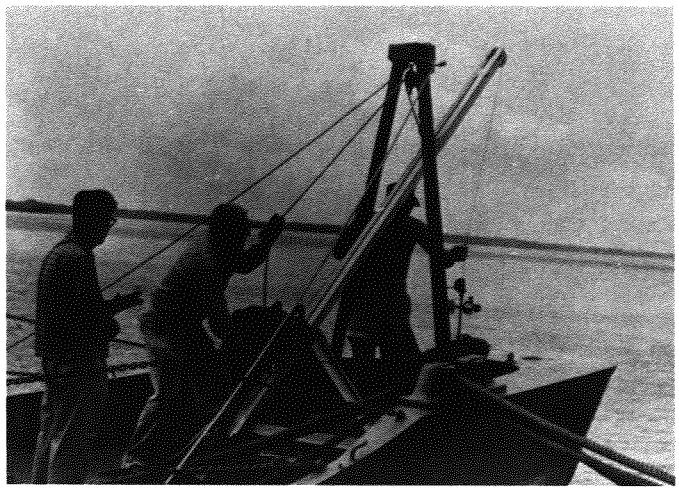

FIGURE 5.—R. E. Olfman (center), USGS hydrologist and team leader regulating the cable while his colleague, L. C. Davis (right), guides the current meter and water sampler over the side of the ship. A Brazilian hydrologist (left) stands by to provide assistance. A typical Amazon sailing smack passes to the left.

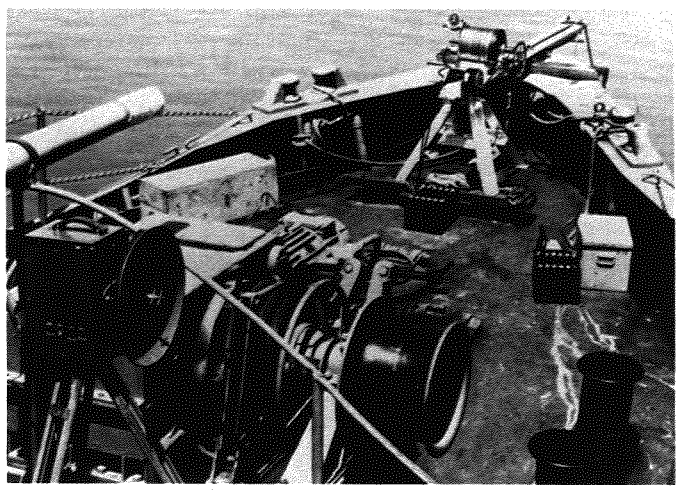

FIGURE 6.—Bow of the Brazilian Corvette, *Mearim*, which plied the Amazon River in July 1963 carrying the USGS team investigating the hydrology of this, the world's greatest river. At the left is the tellurometer unit used for ship-to-shore control measurements. The winch at the bow railing was used for flow measurements, soundings, and water samples.

Amazon River. The dissolved-solids concentration ranged from only 20 to 51 mg/l (milligrams per litre) during the 1963–64 period of observation. The technical results of these investigations were published in USGS Circular 552.

Between 1964 and 1969 the Amazon River was measured three times under the direction of the National Department of Water and Electrical Energy (DNAEE) and with the assistance of USGS hydrologists attached to DNAEE under US AID auspices. Most recently on November 27, 1969, G. F. Smoot, USGS hydrologist, demonstrated the "moving-boat" method of streamflow measurement on the Amazon River at Óbidos with the assistance of DNAEE hydrologists. Past individual measurements of the river at this gaging station by conventional methods have required 1½ to 2 days to complete. Individual measurements by the "moving-boat" method, of comparable accuracy, required only about 20 minutes each.

NATIONAL WATER RESOURCES PROGRAM, 1967–70

Although the regionally oriented water-resources investigations program in northeast Brazil had been operating successfully through USGS support to SUDENE and other agencies and under US AID grant financing, a policy decision was made in 1966 (1) to de-emphasize support of regional development programs and increase support of national programs and (2) to change over the financing of technical assistance in Brazil from grant to loan funding. As a result of this decision, the USGS in concert with US AID and the Brazilian agencies concerned designed a 10-year master plan for a long-term program of minerals and water-resources investigations, based on US AID loan financing, and successfully negotiated an agreement with the Brazilian Ministry of Mines and Energy (MME) as the counterpart. The loan agreement was signed in December 1967. The loan agreement included provision for water-resources projects with two departments of the MME, one in surface-water investigations with the National Department of Water and Electrical Energy, and the other in ground-water investigations with the National Department of Mineral Production (DNPM). The surface-water project was identified as "Hydrologic Data Collection and Analyses (DNAEE no. 1)" and the ground-water project as "Ground-Water Project-Northeast Brazil (DNPM no. 5)."

Surface-water investigations.—Preliminary formulation of technical support needs in Brazil's national program of surface-water investigations was first made in July 1964 by L. J. Snell, USGS hydrologist, who reviewed the activities of the former Division of Waters of the DNPM. (This division subsequently was changed into the National Department of Water and Electrical Energy or DNAEE in December 1965.) The organizational needs for functions and operations in surface-water hydrology of the newly established DNAEE were studied in depth by A. H. Williams, USGS hydrologist, during the

first 3 months of 1966 and described in detail in his report of March 1966.

Active USGS technical support of the new DNAEE was begun under interim US AID grant funding in February 1966, when F. F. LeFever, USGS hydrologist, arrived in Rio de Janeiro to take up his duties as senior advisor in hydrology to DNAEE. The principal project objectives included (1) expansion and improvement of the field network of streamflow, sediment, rainfall, and evaporation stations, (2) field and office training of DNAEE hydrologists in 10 active regional districts, (3) computation, evaluation, and publication of a backlog of streamflow and other hydrologic data, and (4) annual compilation and publication of hydrologic data. Mr. LeFever remained in Brazil until September 1966, when he returned to the U.S.A. During his tenure, however, he concentrated on strengthening the headquarters organization of DNAEE in Rio de Janeiro and counseling DNAEE on organizational, staffing, equipment, and publication needs.

In April 1967, G. N. Mesnier, USGS hydrologist, was assigned to the project to continue the work of Mr. LeFever. He completed his assignment, returned to the U.S.A. in February 1969. In April 1967, C. L. Lawrence, USGS hydrologist, also was assigned to advise DNAEE on technical problems in hydrologic-data collection, in improving operational procedures used by DNAEE, and in training personnel. Mr. Lawrence completed his assignment and returned to the domestic program of the USGS in July 1969. W. W. Evett, USGS hydrologist, arrived in Rio de Janeiro in July 1969 to take up the duties of senior advisor in hydrology to DNAEE and to carry on the work of Mr. Mesnier, and in July 1970, D. C. Perkins, USGS hydrologist, arrived in Brazil to take up the work of Mr. Lawrence.

On termination of formal USGS technical support of SUDENE surface-water investigations in December 1967, W. F. Curtis was transferred from Recife to Rio de Janeiro to begin work on the hydrologic program of the DNAEE. During the remaining 7 months of his 2-year tour in Brazil, Mr. Curtis visited the district offices of DNAEE in Niterói, Belo Horizonte, Salvador, Belém, and Manaus to demonstrate the use of hydrologic field equipment previously provided DNAEE under US AID grant funding. He also designed a new Sediment Analysis Laboratory for the DNAEE at Belo Horizonte and selected equipment for the laboratory. Mr. Curtis returned to the USGS domestic program in September 1968. He again visited Brazil on a 1-month assignment in November 1969 to assist in the inauguration of the laboratory on November 17, 1969. The laboratory has a regional function, processing sediment samples for DNAEE from south-central Brazil.

In August 1969, L. J. Snell returned to Brazil on a 3-month assignment to review current operations of the Division of Waters in 10 of the 12 operating DNAEE districts. Mr. Snell's report of December 1969 described in depth the specific staffing, operational and quality-control problems in the stream-gaging programs of the DNAEE district offices and at the Rio de Janeiro headquarters, and presented nine recommendations for improvements. Mr. Snell returned again to Brazil in February 1970 on a 4-month assignment to assist on an intensive on-the-job training emphasizing computation of streamflow data in the individual DNAEE districts. He returned to the U.S.A. in June 1970.

Also in November 1969, G. F. Smoot, USGS hydrologist, spent 2 weeks in field seminars and demonstrations of the moving-boat method of stream gaging to Brazilian hydrologists of the DNAEE. During his stay in Brazil, Mr. Smoot gave field seminars with the participation of 25 DNAEE hydrologists at Pirapora on the Rio São Francisco in Minas Gerais and also at Óbidos on the Amazon River.

Ground-water investigations.—Under the loan agreement a "Ground Water Project-Northeast" (DNPM No. 5) had been identified for implementation in the Ground Water Section of DNPM's Fourth District, whose activities in 1971 were directed toward drilling production water wells for private individuals and companies as well as for municipalities and other governmental agencies in northeast Brazil. This activity is carried on in competition with the drilling operations of 28 or more other public and private agencies. DNPM project No. 5 was designed to build within DNPM a competence and capability for areal ground-water appraisal and investigation coupled with guided exploratory drilling for hydrogeologic data. The leadership of the DNPM Fourth District, however, proved largely interested in production well drilling; consequently, the project was not implemented.

Owing to administrative delays, technical support of the national surface-water program was slow in gaining momentum. Not until July 1969 did the program become fully operative. As of 1971, however, the program was well underway and moving toward the goal of a national hydrologic network on all the major rivers in Brazil. A national program of areal ground-water investigations was still an unattained goal in 1971 in Brazil but is much to be desired. As

of 1971, SUDENE in northeast Brazil was the chief governmental organization that was actively conducting systematic ground-water investigations of the type that are needed in many other critical areas of Brazil for proper appraisal of the needs and limits of irrigation, public, industrial, and rural water supply.

References

Araujo, J. M. de C., and Rodis, H. G., 1965, Reconhecimento no Vale Açu do Rio Piranhas [abs.]: XIX Congresso Brasileiro de Geología avluso, no. 40., p. 39–40, Rio de Janeiro.

Cederstrom, D. J., and Assad., J. C., 1962, 1962, Observations on the hydrology of Northeast Brazil: U.S. Geol. Survey open-file rept., 41 p., 6 figs.

——— 1964, Observaçoes hidrológicas no Nordeste do Brasil: Brazil, Div. Geologia e Mineralogia, Notas Prelim. e Estudos 120, 42 p., 6 figs.

Davis, L. C., Jr., 1964, The Amazons' rate of flow: Natural History, v. 73, no. 6, p. 14–19; (in Danish) Naturens Verden, p. 289–297, October 1965.

——— 1968, Correcting river velocities measured from an unanchored ship (Amazon River, Brazil), *in* Selected techniques in water-resources investigations, 1966–67: U.S. Geol. Survey Water-Supply Paper 1892, p. 109–113.

Departamento Nacional de Obras Contra as Secas and Superintência do Desenvolvimento do Nordeste, 1968a, Compilação dos dados hidrologicos do Nordeste (Brasil), 1910–64; DNOCS and SUDENE, v. I, 335 p., 1 fig. (Compiled under the guidance of R. O. R. Martin and W. F. Curtis, U.S. Geol. Survey.)

——— 1968b, Compilação dos dados hidrologicos do Nordeste (Brasil3, 1910–64; DNOCS and SUDENE, v. II, 327 p., 1 fig. (Compiled under the guidance of R. O. R. Martin and W. F. Curtis, U.S. Geol. Survey.)

Chada, L. G. F., Pessoa, M. D., and Sinclair, W. C. 1966, Hydrogeology of the Upper Capibaribe Basin, Pernambuco, Brazil: U.S. Geol. Survey Water-Supply Paper 1663–E, p. E1–E44, 1 pl., 3 figs. [1969].

——— 1967, Hidrogeología da Bacia do Alto Capibaribe, Pernambuco: Brazil, SUDENE, Bol. Recursos Naturais, v. 5, no. 1, p. 29–87, 10 figs.

Oltman, R. E., 1965, Some observations of Amazon River hydrology: South Carolina Engineer, v. 16, no. 1, p. 6–12.

——— 1967, Reconnaissance investigations of the discharge and water quality of the Amazon: Atlas do Simposio sobre a Biota Amabonica, v. 3 (limnolgia), p. 163–185.

——— 1968, Reconnaissance investigations of the discharge and water quality of the Amazon: U.S. Geol. Survey Circ. 552, 16 p., 8 figs.

Oltman, R. E., Sternberg, O'R. H., Ames, F. E., and Davis, L. C., Jr., 1964, Amazon River investigations reconnaissance measurements of July 1963: U.S. Geol. Survey Circ. 486, 15 p., 4 figs.; 1964; (in Portuguese) Brazil, Dept. Nac. Produção Mineral, Div. de Aguas, Divulgação Tecnica, no. 1, p. 18–74, 4 figs.

Parde, Maurice, and Oltman, R. E., 1967, Nouvelles données experimentales et evaluations sur les debits de l'Amazone (Brazil): Acad. Sci. Comptes Rendus Paris, v. 264, p. 1401–1406.

Rodis, H. G., and Araujo, J. M., de C., 1968, Ground-water resources of the Açu Valley, Rio Grande do Norte, Brazil: U.S. Geol. Survey Water-Supply Paper 1663–C, 34 p., 1, pl., 2 figs.

Rodis, H. G., and Suzinski, Edson, 1972, Ground water in the Teresina-Campo Maior area, Piaui, Brazil: U.S. Geol. Survey Water-Supply Paper 1663–G, 34 p., 1 pl., 2 figs.

Schneider, Robert, 1963, Ground-water provinces of Brazil: U.S. Geol. Survey Water-Supply Paper 1663–A, 14 p., 1 pl.

Schoff, S. L., 1962, Hydrologic investigations for Northeastern Brazil: U.S. Geol. Survey open-file rept., 67 p., 5 figs.

——— 1971, Origin of mineralized ground water in Precambrian rocks, northeast Brazil *in* Geological Survey research 1971: U.S. Geol. Survey Prof. Paper 750–B, p. B244–B247.

——— 1972, Origin of mineralized water in Precambrian rocks of the Upper Paraíba basin, State of Paraíba, Brazil: U.S. Geol. Survey Water-Supply Paper 1663–H, 38 p., 1 pl., 3 figs.

Superintendência do Desenvolvimento do Nordeste (Brazil), Division of Hydrology, 1969a, Dados pluviométricos mensais, "In Natura": SUDENE, DNOCS, EME, DNAEE, v. 1, 502 p. (Compiled with the assistance of G. E. Philipsen, R. O. R. Martin and W. F. Curtis, U.S. Geol. Survey.)

——— 1969b, Dados pluviométricos mensais, "In Natura": SUDENE, DNOCS, EME, DNAEE, v. 2, 478 p. (Compiled with the assistance of G. E. Philpsen, R. O. R. Martin and W. C. Curtis, U.S. Geol. Survey.)

——— 1969c, Dados pluviométricos mensais, "In Natura": SUDENE, DNOCS, EME, DNAEE, v. 3, 352 p. (Complied with the assistance of G. E. Philpsen, R. O. R. Martin and W. F. Curtis, U.S. Geol. Survey.)

CHILE

Extending north-south for 4,270 km along the Pacific Coast of South America and averaging only slightly more than 160 km wide between the crest of the Andes and the ocean, Chile is a land of tremendous climatic and geographic diversity. It ranges from the bleak and barren Atacama Desert in the north through the mild and sunny valleys of central Chile to the icy fiords of Tierra del Fuego in the south. For the past 25 years the USGS has participated in the U.S. bilateral program of economic aid and technical assistance in Chile, which aggregated more than $1 billion prior to 1969. Beginning first with reconnaissance-type ground-water studies in the middle and late 1940's, the USGS assistance evolved to more intensive hydrogeologic investigations and institutional development in the 1950's and early 1960's. In recent years (1969–70), the USGS assisted in designing a national water-data system and a computerized total water-resources evaluation of the Río Aconcagua Valley, which is typical of the transverse valleys of central Chile. The scope, objectives, and accomplishments of the assistance during 1945–70 are described in following sections.

Ground-Water Reconnaissance in Central and Northern Chile, 1945–48

Owing to restrictions on imported foodstuffs engendered by shipping shortages during World War II and to economic stagnation in northern Chile resulting from the decline of the nitrate industry, the Government of Chile, in the postwar period, embarked on an extensive program of agricultural and water-resources development aimed at broadening the economic base and agricultural self-sufficiency of the region. This program, financed by loans from the Export-Import Bank to the Chilean Corporación de Fomento de la Producción (CORFO), gave considerable emphasis to pump irrigation from wells, particularly in central and northern Chile.

To establish guidelines for ground-water exploration and development and to evaluate ground-water potentials in various parts of central and northern Chile, the CORFO (Chilean Development Corp.) requested technical assistance of the U.S. Government through the Department of State. S. S. Nye, USGS hydrogeologist, was assigned to the Irrigation Section of CORFO to undertake the work in late 1945 under the program of the Interdepartmental Committee on Scientific and Technical Cooperation. Owing to illness, however, he was compelled to return to the United States and was replaced by G. C. Taylor, Jr., also a USGS hydrogeologist, who arrived in Chile in May 1946.

Mr. Taylor continued in Chile until January 1948 and during his stay completed surveys and appraisals of the ground-water resources of 26 valleys and basins in northern Chile. These included: studies of the Lluta, Azapa, Chaca, Camarones, and Tana Valleys, the Pampa del Tamarugal, Pica Oasis, Río Loa Valley, and the San Pedro de Atacama area, all in the "Norte Grande" region; and the Domeyko, Algarrobal, Paipote, Chañaral Alto, Aucó, Quilimarí, Lagunillas, and Los Choros Valleys, the Tongoy area, Pocuro, Putaendo, Catemu, Melón, Puchuncavi, La Ligua and Petorca Valleys, all in the "Norte Chico" region. In addition, ground-water surveys were made of the Casablanca, Chacabuco, Yali, and Pangué valleys in central Chile. USGS open-file reports on all these surveys and appraisals were also translated into Spanish for more effective use in Chile. Since their release in 1946–47 these reports have formed an important base of departure for more recent and more intensive ground-water exploration and development by CORFO, other Chilean government agencies, and private companies.

Ground-Water Investigations in the Río Elqui Valley and the Huachipato-Talcahuano Area, 1950

Engineering feasibility and cost-benefit ratio studies made in 1949 by the Frederick Snare Corp., consulting engineers of New York, pointed up the lack of good dam and reservoir sites in the Río Elqui Valley (fig. 7), owing to the considerable thickness and permeability of the valley fill, the steep stream gradients, and the high rate of siltation. Test drilling for foundation studies indicated, however, a high permeability of the valley fill and a probable potential for ground-water development.

To evaluate this potential, the Chilean Corporación de Fomento de la Producción through the Department of State requested the services of a USGS ground-water hydrologist. P. H. Jones, hydrogeologist assigned to the project, made a detailed field examination of the Río Elqui Valley and the adjacent area in the "Norte Chico" region of Chile in March and April 1950. In his report of January 1951, Mr. Jones recognized (1) that quantitative studies were needed before intensive development of the ground-water resources could be undertaken, (2) that the ground-water resources were indeed large and capable of much greater exploitation than that then (1950) extant, and (3) that the best approach to optimum development of the water resources of the valley was through use of the ground-water reservoir in the valley fill to balance surface-water inflow and outflow.

Mr. Jones in March 1950 also made a brief reconnaissance of the Huachipato-Talcahuano area in central Chile to outline requirements for ground-water

FIGURE 7.—Valley of the Río Elqui from point east of La Serena. Snowcapped Andes Mountains in the background. Terraced irrigated vineyards on the left.

exploration for the industrial water supply of CORFO's Compañía de Acero del Pacífico steel mill and submitted a report on his findings.

NATIONAL GROUND-WATER INVESTIGATIONS PROGRAM, 1955–62

A long-term program of ground-water investigations and related institutional development in Chile was begun in May 1955, as part of countrywide geological, minerals, and ground-water investigations, technically supported by the USGS and under the sponsorship of US AID and its predecessor agencies. The principal Chilean counterpart agencies during the life of the program were the Corporación de Fomento de la Producción, which traditionally has been concerned with the exploration and development of the nation's ground-water resources, and the more recently established (December 1957) Instituto de Investigaciones Geológicas (IIG), which has been concerned chiefly with surveys, appraisals, and investigations of mineral and ground-water resources and geologic mapping. The Dirección de Riego and the Dirección de Obras Sanitarias, both in the Ministerio de Obras Públicas, were also involved at times in ground-water exploration related to project activity. Financed by US AID grant funds, the USGS support of the ground-water investigations program was continued over a 7-year term and was phased out in June 1962.

R. J. Dingman, USGS hydrogeologist, arrived in Chile in May 1955 to begin the ground-water program and during the following few months moderately intensive ground-water investigations were begun near the Pica Oasis, in the Pampa del Tamarugal, in the San Pedro de Atacama region (fig. 8), and the Santiago basin, all of which had been assigned priority for investigation and development by CORFO and later IIG. After a decision in 1958 to expand the scope of the ground-water investigations, W. W. Doyel and R. J. Devaul, USGS hydrogeologists, were assigned to the program. They arrived in Chile in February 1959. Mr. Devaul returned to the United States in December 1961 and Mr. Doyel in April 1962.

Active fieldwork continued in the Pica area under Mr. Dingman's direction until December 1956. The report on the area, published in Spanish by the IIG in 1962, presents a detailed geologic map of the area, a description of the geology, the results of exploratory drilling, a complete well inventory, a semiquantitative evaluation of the ground-water resources, and recommendations for their development. Fieldwork on a similar but somewhat more intensive investigation in the San Pedro de Atacama region was

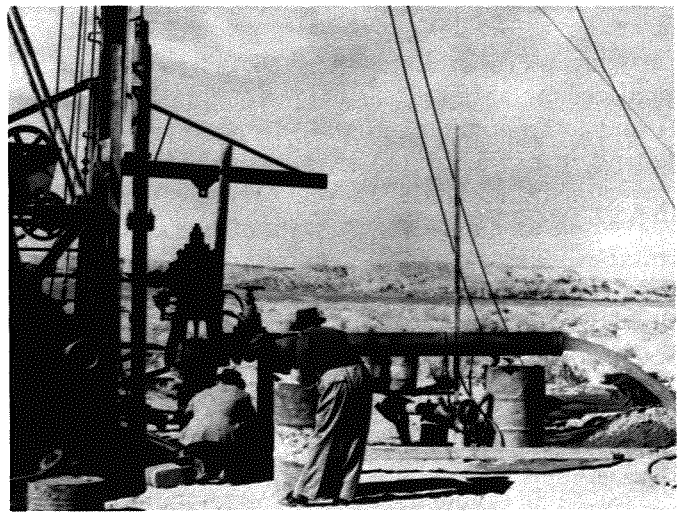

FIGURE 8.—Chilean engineers making observations at well 6, about 2 km northeast of San Pedro de Atacama. The well drilled to a depth of 246 m flowed naturally, but discharge has been increased by the installation of a pump. This well is one of several put down to explore an artesian system in the northern part of the Atacama Basin under the guidance of R. J. Dingman, USGS hydrogeologist.

continued until June 1962, and two reports were published on this region by IIG in 1963 and 1965, respectively. A ground-water reconnaissance of the Pampa del Tamarugal basin under Mr. Dingman's guidance was completed by Octavio Castillo U., IIG hydrogeologist, in June 1957, and the results were published in IIG Bulletin 5 in 1960. This report contains a complete well inventory, a water-table map, an evaluation of ground-water quality, a semiquantitative analysis of the probable rates of recharge and discharge from the ground-water reservoir, and recommendations for further ground-water development in the basin.

Fieldwork on an intensive and continuing investigation of the ground-water resources of the Santiago Basin, begun by Mr. Dingman in 1955, was later continued under the guidance of Mr. Doyel until the termination of USGS technical assistance in 1962. Two reports on the Santiago Basin were published by the IIG covering the 7-year term of USGS technical support. The first report, of a preliminary nature and released in 1958 as IIG Bulletin 1, covers an area of some 720 km^2 in the vicinity of the city of Santiago. This report contains a brief description of the hydrogeology of the Santiago area, tables of well records, a well location map, and chemical analyses of the ground water. The second report released in 1963 as IIG Bulletin 15, described in detail the ground-water geology and hydrology of the Santiago

Basin. This report pointed out that, as of 1961 and with an average rate of withdrawal of 3.2 m^3/s, ground-water levels were declining at an average of 1 m per year in the central part of Santiago. At the same time the ground-water reservoir in the peripheral areas of the basin was underdeveloped. The report recommended limited development of those areas but legislative control of further well drilling in the central part of the city. As of 1961, withdrawal of ground water for municipal and industrial purposes amounted to 32 percent of the water use in the Santiago urban area. Throughout the 1960's Chilean engineers (fig. 9) and hydrogeologists continued detailed studies of the geology and hydrology of the Santiago Basin that led in 1970 to publication of a comprehensive atlas entitled, "Hidrogeología de la Cuenca de Santiago" under the auspices of IIG and CORFO with Señores Falcón, Castillo, and Valenzuela as principal contributors.

Mr. Dingman also began hydrogeologic studies and exploratory drilling in the Arica area, which covers 125 km^2 in the lower Lluta Valley, the lower Valle de Azapa and the Concordia just south of the Peruvian border. The work, continued and completed under Mr. Doyel's direction, included collection of lithologic and water-quality data and aquifer tests at 14 exploratory wells, a well inventory of the Azapa Valley, and an observation-well program. A report on the Arica area by Mr. Doyel was published by the USGS in 1964.

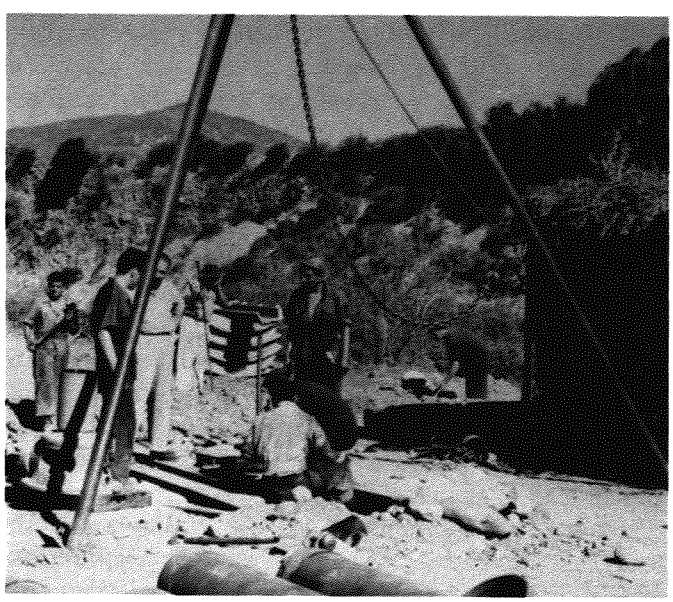

FIGURE 9.—Chilean engineers and technicians preparing to set pump on new well near the Río Maipo southeast of Santiago.

Messrs. Dingman, Doyel, and Devaul also directed preliminary hydrogeologic studies and exploratory drilling by IIG and CORFO personnel in the Calama area; Copiapó Valley; Chillán (fig. 10), Temuco, and Tongoy areas; and Aconcagua Valley during their stay in Chile, but these studies were not carried to the stage of formal reporting during the life of the support program.

During the last 2 years of his stay in Chile and until the phaseout of USGS support and his return to the United States in June 1962, Mr. Dingman served as chief-of-party of the combined USGS geological, minerals, and ground-water team. Mr. Doyel in this period gave leadership to the USGS support in ground-water activities. With the assistance of CORFO and IIG personnel, he completed a Spanish-English glossary of 700 ground-water and related hydrologic terms and began an observational program of ground-water levels in the developed areas of Chile. He directed a pilot-type inventory of the industrial and public water supplies of Coquimbo Province, which was released as an IIG open-file report in 1962. He also participated in ground-water studies in the Puntas Arenas region of southern Chile, the Quebrada de Los Choros, and Quebrada de Tarapacá and in special hydrogeologic studies of damage in the Valdívia area caused by the major earthquake of May 22, 1960, in south-central Chile.

Throughout their stay in Chile, considerable attention was directed by Messrs. Dingman and Doyel toward the education and training of Chilean geologists and engineers through a 4-year series of seminars and formal courses in ground-water geology and hydrology in the Schools of Geology and of Engi-

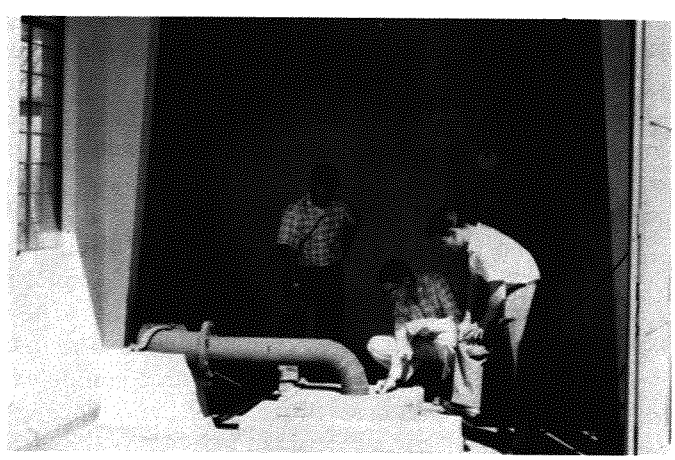

FIGURE 10.—Chilean engineers making water-level measurements in municipal well at Chillán under the guidance of R. J. Devaul, USGS hydrogeologist.

neering at the University of Chile in Santiago. They also trained IIG and CORFO personnel in techniques and methodology during the progress of fieldwork in areal ground-water investigations. At the phase-out of USGS support in June 1962, the ground-water staff of IIG had been increased to five trained professionals and to eight professionals in CORFO's Ground Water Section, all of whom had been trained to a high level of technical competence by the USGS team.

Overall, the USGS ground-water group in its 7-year term (1955–62) of technical support was markedly successful in building a strong and viable scientific and technical base for ground-water investigations and development in Chile. This success is measured by the fact that Chile in 1970 was playing a leading role in this field among the Latin American nations and was moving ahead effectively in ground-water development and management at a rate commensurate with its general economic growth. The Hydraulic Resources Section of CORFO with a staff of 22 professional engineers, geologists, and technicians currently is the most active governmental agency in Chile in ground water as well as in overall water-resources investigations and development. The Direcciónes de Riego and Obras Sanitárias, each with a staff of several professional engineers, also had moderate involvement in this field as of 1970. The IIG, however, has relinquished somewhat its former position in ground-water investigations in favor of concentration on minerals investigations and geologic mapping, and some of its personnel in the ground-water sector have moved to the CORFO staff.

A further measure of the success of the USGS technical support since 1946 is CORFO's record in ground-water discovery and development in Chile. Between 1949 and 1962, for example, CORFO put down 357 production wells for an aggregate depth of about 25,000 m and a total tested yield of 19.55 m^3/s. This development resulted in a potential increase in irrigated land of 17,000 ha (hectares), the solution of the water-supply problems for 67 industries, and the provision of potable water supplies to 300,000 people. In addition, the success of exploratory drilling in unproven areas has created a new field for private well-drilling contractors and has resulted in the establishment of several competent well-drilling contractors. Since 1962 and through 1970 this rate of growth continued. Also, the prolonged drought of 1967–69 greatly accelerated ground-water exploration and development particularly in the valleys of central Chile where, traditionally, irrigated agriculture has been sustained mostly by diversions from streams.

National Hydrologic Data System, 1969

During 1967–69 most of central Chile suffered from a prolonged drought that was perhaps the most severe in the recorded history of the region. To cope with the problems induced by the drought, the Chilean government organized an interdepartmental Special Drought Commission composed of representatives of all the governmental agencies concerned with water resources and related problems. Among others, this commission recognized a compelling need for a National Hydrologic Data System to optimize water-resources investigation, development, and management. To assist in the formulation of this system the commission requested expert U.S. assistance from US AID/Santiago, and W. W. Doyel and M. E. Moss, USGS hydrologists, were assigned to the work. Messrs. Doyel and Moss arrived in Chile early in August 1969 and remained until early in November 1969, at which time a draft of their recommendations was submitted to US AID/Santiago and the Government of Chile.

In their USGS open-file report of November 1969, they (1) outlined in detail the needs for a national hydrologic data system in Chile, including organizing, controlling, and testing the system, and (2) presented 19 recommendations for implementing the system.

Water Resources Investigations in the Aconcagua River Valley and Other Areas, 1969, 1970

The great drought of 1967–69 gave compelling impetus to the exploration and development of ground water in the river valleys of central Chile that traditionally have been irrigated from "run-of-the-river" diversions. The drought, moreover, brought into focus the great potential for utilizing subsurface storage by pumping water from the permeable alluvial fills of these valleys to balance seasonal variations in surface-water runoff and availability. To evaluate these potentials, the Government of Chile established a joint study team composed of members from the Dirección de Riego, the Servicio Agrícola y Ganadero, the Empresa Nacional de Electricidad, S.A., and the Instituto de Investigaciones Geológicas to undertake a pilot water-resources systems study of the Aconcagua River Valley under the leadership of the Hydraulic Resources Department of CORFO. This study began in 1967, and since that time engineers and geologists of the Chilean study team have obtained a large fund of information on the configuration of the water table, the shape of

the bedrock surface of the valley thalweg, and the thickness and transmissivity of the aquifer.

In mid-1969, the Chilean Government requested US AID/Santiago to provide technical assistance in setting guidelines for systems analysis studies of optimum conjunctive use of the water resources of the Aconcagua Valley. J. E. Moore, USGS hydrologist assigned to the project, arrived in Chile in October and remained until the end of December 1969. In his USGS open-file report of December 1969 he recommended a 2-year study program under CORFO leadership that included collection and analysis of all available hydrologic and hydrogeologic data, construction and calibration of a digital simulation model of the valley, and use of the model to evaluate alternative plans for development. These recommendations provide sound guidelines for optimizing water management in other river valleys of central Chile and the "Norte Chico" region. While in Chile, Mr. Moore also made reconnaissance of water resources in the Limarí, Chimbarongo, and Yali Valleys where the Dirección de Riego is currently (1970) developing ground water for supplemental irrigation.

During October 1969, J. D. Winslow, USGS hydrologist, visited Chile and the Aconcagua Valley project. During his stay he reviewed applications of USGS digital-model studies of hydrologic systems to the problems of the Aconcagua Valley. He also conferred with Mr. Moore and Chilean hydrologists of CORFO on compatibility of USGS digital-model programs with computers installed in Chile.

Following Mr. Moore's work, the CORFO in early 1970 again requested US AID/Santiago to provide short-term USGS assistance in the Aconcagua Valley project. O. J. Taylor, USGS hydrologist, was assigned from August to October 1970 to demonstrate applications of digital modeling for simulation of the effects of recharge and discharge on streamflow and ground-water storage in a selected reach of the valley, known as Hijuelas. In his USGS open-file report of October 1970, Mr. Taylor presented the results of preliminary digital-model studies of the Hijuelas reach. These model studies demonstrated that (1) withdrawals from wells reduced ground-water storage, (2) return flows to the river peaked at or shortly after the end of the irrigation season, and (3) return flow was less after conjunctive use of surface water and ground water. Mr. Taylor recommended preparation of comparable calibrated digital models of the entire Aconcagua Valley to analyze the effects of additional ground-water development, to evaluate the effects of proposed surface-water reservoirs, and to plan optimal utilization of the total water resources.

References

Castillo U., Octavio, Falcón M., Eduardo, Doyel, W. W., and Valenzuela M., Manuel, 1963, El agua subterránea de Santiago (Segundo Informe, 1958–62): Chile Inst. Inv. Geol. Bol. 15, 65 p., 5 illus., 16 figs.

Dingman, R. J., 1962, Tertiary salt domes near San Pedro de Atacama, Chile, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–D, p. D92–D94.

——— 1963a, Cuadrángulo Tulor, Província de Antofagasta: Chile Inst. Inv. Geol., Carta Geol. Chile, no. 11, 37 p., 1 map.

——— 1963b, Reversal of throw along a line of low-angle thrust faulting near San Pedro de Atacama, Chile, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–E, p. E25–E27.

——— 1963c, Formation of "salt cups" near San Pedro de Atacama, Chile, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–E, p. E103–E104.

——— 1965a, Geology and ground-water resources of the Pica area, Tarapacá Province, Chile: U.S. Geol. Survey Bull. 1189, 113 p., 2 pls., 19 figs.

——— 1965b, Pliocene age of the ash-flow deposits of the San Pedro area, Chile, *in* Geological Survey research 1965: U.S. Geol. Survey Prof. Paper 525–C, p. C63–C67.

——— 1965c, Cuadrángulo San Pedro de Atacama, Provincia de Antofagasta: Chile Inst. Inv. Geol., Carta Geol. Chile, no. 14, 29 p., 1 map.

——— 1967, Geology and ground-water resources of the northern part of the Salar de Atacama, Antofagasta Province, Chile: U.S. Geol. Survey Bull. 1219, 49 p., 1 pl., 11 figs.

Dingman, R. J., and Barraza, S., Lorenzo, 1958, El agua subterránea de Santiago (Informe Preliminar): Chile Inst., Inv. Geol. Bol. 1, 13 p., 1 fig.

Dingman, R. J., and Lohman, K. E., 1963, Late Pleistocene diatoms from the Arica area, Chile: U.S. Geol. Survey Prof. Paper 473–C, p. C69–C72.

Donoso, R., Jaime, and Dingman, R. J., 1962, Contribución de la Corporación de Fomento al desarrollo de agua subterránea en Chile: Chile Inst. Inv. Geol. Carta Geol. Chile, v. 3, nos. 2–5, 125 p., 4 maps.

Doyel, W. W., 1961, Ground-water possibilities in the lower part of the Quebrada Tarapacá, Chile: U.S. Geol. Survey open-file rept., 4 p., 1 fig.

——— 1962, Ground-water possibilities in the Quebrada Los Choros, Chile: U.S. Geol. Survey open-file rept., 6 p.

——— 1964, Ground water in the Arica area Chile, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–D, p. D213–D214.

Doyel, W. W., and Castillo U., Octavio, 1964, The artesian aquifer of the Tierra del Fuego area, Chile, *in* Geological Survey research 1964: U.S. Geol. Survey Prof. Paper 501–B, p. B169–B172, 1 fig.

Doyel, W. W., Castillo U., Octavio, Donoso R., J., y Alamos, C. F., 1962, Antecedentes preliminares sobre posibilidades de agua subterranea en el area de Punta Arenas (Punta Arenas-Puerto Natales y parte norte de la Isla Grande de Tierra del Fuego): Chile Inst. Inv. Geol. open-file rept., 12 p. 1 fig.

Doyel, W. W., Dingman, R. J., and Castillo U., Octavio, 1964, Hydrogeology of the Santiago area, Chile, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–D, p., D209–D212.

Doyel, W. W., Emparán C. C., Valenzuela M., M., y Lahsen A., A., 1962 Abastecimiento de agua potable e industrial de la Provincia de Coquimbo, Chile: Chile Inst. Inv. Geol. open-file rept., 60 p., 7 figs.

Doyel, W. W., Moraga, B. A., Falcón, M. E., 1960, Relaciónes entre la geología de Valdivia (Chile) y los danos causados por los terremotos del 22 Mayo de 1960, informe preliminar: Chile Inst. Inv. Geol. open-file rept., 19, p. 6 figs.

——— 1963, Relation between the geology of Valdivia, Chile, and the damage produced by the earthquake of 22 May 1960: *In* Oceanog., Geol., and Eng. Studies Chilean Earthquakes, May 1960: Seismol. Soc. America Bull. Spec. Issue, v. 53, no. 6, p. 1331–1345.

Doyel, W. W., and Moss, M. E., 1969, A national hydrologic data system for Chile: U.S. Geol. Survey open-file rept., 141 p., 1 fig.

Galli O., Carlos, and Dingman, R. J., 1962, Cuadrángulos Pica, Alca, Matilla, y Chacarilla, con un estudio sobre los recursos de agua subterranea, Província de Tarapacá; Chile Inst. Inv. Geol., Carta Geol. Chile, v. 3, nos. 2–5, 125 p., 4 maps.

Jones, P. H., 1950, Memorandum on ground-water conditions in Huachipato-Talcahuano area, near Concepción, Chile: U.S. Geol. Survey open-file rept., 8 p., 5 figs., 1 map.

——— 1951, Geology and ground-water conditions in the lower valley of the Río Elqui of Chile: U.S. Geol. Survey open-file rept., 90 p., 6 pls., 40 figs.

——— 1953, Geology and ground-water conditions in the lower valley of the Río Elqui of Chile: Econ. Geology, v. 48, no. 6, 457–491.

Lemke, R. W., Bowes, W., Thomas, H. E., and Bravo S., Nelson, 1963, Relation between geology and the damage in Puerto Montt, Chile, caused by the earthquake of 22 May 1960: In Oceanog., Geol., and Eng. Studies Chilean Earthquakes, May 1960: Seismol. Soc. America Bull. Spec. Issue, v. 53, no. 6, p. 1299–1314.

Moore, J. E., 1969, Water-resources investigation program for Río Aconcagua Valley, Chile: U.S. Geol. Survey open-file rept., 62 p., 15 figs.

Post, A. S., 1970, Glaciers of the Central Chilean Andes and their importance to the water resources: U.S. Geol. Survey open-file rept., 5 p., 1 fig.

Taylor, G. C., Jr., 1947a, Ground water in the valleys of Aconcagua and northern Valparaiso provinces, Chile: U.S. Geol. Survey open-file rept., 35 p., 5 figs.

——— 1947b, Ground-water studies in the Province of Antofagasta, Chile: U.S. Geol. Survey open-file rept., 25 p., 3 figs.

——— 1947c, Ground-water studies in the Province of Atacama, Chile: U.S. Geol. Survey open-file rept., 18 p., 5 figs.

——— 1947d, Ground-water studies in the Province of Coquimbo, Chile: U.S. Geol. Survey open-file rept., 22 p., 6 figs.

——— 1947e, Ground-water studies in the Tarapacá Province, Chile: U.S. Geol. Survey open-file rept., 46 p., 11 figs.

——— 1948, Geology and ground water of the Casablanca Basin, Chile: Econ. Geology, v. 33, no. 8, p. 661–674, 4 figs.

——— 1948a, Ground water in the Huechún area of the Chacabuco Basin, Province of Santiago, Chile: U.S. Geol. Survey open-file rept., 4 p., 1 map.

——— 1948b, Ground water in the basin of the Estero Yali, Province of Santiago, Chile: U.S. Geol. Survey open-file rept., 4 p., 1 map.

——— 1948c, Ground water in northern Chile, a summary: Internat. Union Geodesy Geophysics, Internat. Assoc. Sci. Hydrology Cong., Oslo, 1948, Proc., p. 248–255.

——— 1949, Geology and ground water of the Azapa Valley, Province of Tarapacá, Chile: Econ. Geology, v. 44, no. 1, p. 40–62, 5 figs.

Taylor, O. J., 1970, Preliminary digital model studies of the Río Aconcagua Valley, Chile: U.S. Geol. Survey open-file rept., 37 p., 8 figs.

COSTA RICA

A major and prolonged eruption of Irazú Volcano northeast of San José, Costa Rica, which began in March 1963, caused considerable loss of life, heavy ash accumulations over an area of more than 2,400 km^2, and extensive damage to agricultural lands, roads, and, particularly, vulnerable surface-water supplies. Based on preliminary studies in September 1963, the Government of Costa Rica requested technical assistance of US AID/San José, and the USGS was asked to undertake long-term investigations, beginning in April 1964, of the volcanic phenomena of the Meseta Central Occidental and their immediate and potential hazards to the economy of the region.

As a phase of these investigations, the Costa Rican government requested the short-term services of a ground-water expert to advise the Servicio Nacional de Acueductos y Alcantarillado (SNAA) or National Water Supply and Sewerage Service on problems related to ground-water development and water-supply protection and to design a program of ground-water exploration and investigations. W. D. E. Cardwell, USGS hydrogeologist, was assigned to the work and during his stay (August–October 1964) in Costa Rica completed a ground-water reconnaissance of the Meseta Central Occidental and advised engineers and geologists of the SNAA, the Instituto Geografico Nacional, and the Oficina de Defensa Civil on special development problems in several parts of the meseta. Mr. Cardwell also advised SNAA on hydrogeologic problems related to exploratory drilling for ground water in the Nicoya Peninsula and in the environs of Las Cañas, Limón, Siquirres, and Puntarenas. He pointed out the development potential of large springs at La Libertad, Ojo de Agua, Potrerillos, and Puente Mulas for municipal water supplies. These springs were subsequently developed by SNAA. His report of November

1964 recommended a 2-year program of hydrogeologic investigations, including requirements for extensive exploratory drilling and related geophysical surveys and institutional development in the SNAA.

Mr. Cardwell's recommendations were incorporated and implemented in a project that began in September 1965 under the auspices of the United Nations (U.N.) with United Nations Development Programme (UNDP) financing. This project included work by four international hydrogeologists assisted by Costa Rican engineers and geologists, drilling of some 30 deep exploratory wells, hydrogeologic training in SNAA, and detailed groundwater development plans for the San José region and two other areas in Costa Rica.

CUBA

Cuba, the "Pearl of the Antilles," lies about 145 km south of the Florida cays. The republic of Cuba includes the main island, which is about 1,190 km long, with an average width of about 95 km, and also some 1,600 smaller offshore isles and cays. U.S. Geological Survey personnel have been assigned for short periods to water-supply investigations in Cuba on several occasions during the past 75 years; where documentation is available, these activities are described in the following sections.

The earliest recorded work from a USGS source on water resources in Latin America was M. L. Fuller's brief paper on the general hydrology of Cuba, with descriptions of the water supplies of the principal towns and cities, and the occurrence of springs and ground water in karstic limestone terranes of the island. Mr. Fuller's paper, published in 1904 in USGS Water-Supply and Irrigation Paper 110, was compiled from miscellaneous field observations of the U.S. Corps of Engineers and USGS geologists during 1899–1902.

Water Resources Investigations in the Guantanamo Bay Area, 1915–16, 1925, 1959–60, 1962–64

With the exception of Fuller's early work and hydrogeologic and hydrologic reconnaissance in the Nicaro area, USGS activities in Cuba have apparently been concentrated in the environs of Guantanamo Bay which is on the south coast about 95 km west of the east tip of the island. Here as a result of a treaty in 1903 with the Republic of Cuba, the United States acquired a 115-km^2 reservation on which was established a U.S. Naval Station. Since its establishment, the USGS, at the request of the U.S. Department of the Navy, Bureau of Yards and Docks, has evaluated water-supply problems and related geologic and hydrologic conditions on several occasions and recommended solutions appropriate to the changing needs of the station.

The earliest work in the Guantanamo Bay area was that of the late O. E. Meinzer, considered by many to be the doyen of ground-water geology and hydrology in the United States. Mr. Meinzer completed a hydrogeologic field reconnaissance of the Naval Station and its environs in November–December 1915. His report released in mid-1916 described in detail the geologic, topographic, and hydrologic framework of the region and included well records and chemical analyses of typical water samples. The report concluded that the ground-water sources were small and recommended emphasis on surface-water reservoirs for day-to-day water-supply requirements. During the spring of 1916, N. H. Darton, USGS geologist, also made brief observations on water-supply conditions in connection with a study of the geology of the Guantanamo Bay region. Mr. Meinzer also returned to Cuba in February 1925 to examine briefly and evaluate geohydrologic problems at a reservoir site in karstic limestone terrane on the Guaso River near Guantanamo Bay.

In 1959, the Navy Department requested the USGS to undertake a detailed assessment of the water resources of the station reservation itself, particularly with reference to the availability of ground water for emergency needs in the event of interruptions of the supply from the Yateras River, 6.4 km northeast of the station. Horace Sutcliffe, Jr., and L. W. Hyde, USGS hydrogeologists, completed this assessment between September 1959 and June 1960. In their report of 1961, they concluded that existing ground-water sources are adequate for short-time emergencies but that no fresh surface-water sources and no deep artesian ground water are available within the reservation boundaries. Also they discovered no new shallow water-table aquifers in the small alluvial valleys in the reservation. Based on recommendations made in October 1962 by Messrs. Sutcliffe and Hyde, the Navy Department constructed eight infiltration galleries tapping the shallow ground water in the alluvial valleys. Later, during January to April 1963, Mr. Sutcliffe, together with S. M. Lang, USGS ground-water hydrologist, returned to the station to study the hydraulic response of the shallow alluvial aquifers to the operation of the infiltration galleries. In their report of 1964, Messrs. Lang and Sutcliffe described in detail the storage capacity of the highly permeable valley fill and recommended further ground-water development in the Cuzco area. They also recommended artificial recharge to build up the

hydraulic head in the alluvial aquifers and to flush out poor quality ground water near the shore.

WATER-RESOURCES INVESTIGATIONS IN THE NICARO AREA, 1953–56

Because of deficiencies in water supply and proposals for operational expansion, the U.S. General Services Administration in early 1953 requested the USGS to undertake a reconnaissance of the water resources of the area adjacent to the government-owned nickel mine and processing plant at Nicaro on the north coast of eastern Cuba. As a first phase of the survey, N. H. Hoy, USGS hydrogeologist, completed a field reconnaissance in March–April 1953 to evaluate possibilities for supplementing the existing supply from the Rio Levisa from ground-water sources and to recommend measures for their effective development and management. His report of April 1953 concludes that ground water is available in surficial sand and gravel deposits of the narrow coastal plain and in permeable zones in the underlying limestone. He recommends a followup program of water-level observations, water-quality monitoring, exploratory drilling, and aquifer testing prior to full development.

A second phase of the water-resources survey was undertaken by A. A. Fishback, USGS hydrologist, who visited the Nicaro area in February–March 1955 to study the Río Levisa, Río Culebra, Arroyo Blanco, and other streams of the area and to install a water-stage recorder near the point of a proposed diversion on the Río Culebra. He returned in September 1955 to make high-water observations on these streams, and in April 1956, J. H. Hartwell, USGS hydrologist, visited the area to complete low-water observations. Their work was summarized in J. K. Searcy's administrative report of June 1956.

References

Fuller, M. L., 1904, Notes on the hydrology of Cuba: U.S. Geol. Survey Water Supply and Irrigation Paper 110, p. 181–199.

Hoy, N. D., 1953, Ground-water reconnaissance in the vicinity of Nicaro, Cuba: U.S. Geol. Survey open-file rept., 12 p. 2 figs.

Meinzer, O. E., 1916, Ground-water conditions in the vicinity of Guantanamo Naval Station, Cuba: U.S. Geol. Survey open-file rept., 67 p., 2 pls., 32 photos., 7 figs.

——— 1925, Report on reservoir site of the Guaso River near Guantanamo Bay, Cuba: U.S. Geol. Survey open-file rept., 30 p., 2 pls., 29 photos.

——— 1933, Geologic reconnaissance of a region adjacent to Guantanamo Bay, Cuba: Washington Acad. Sci. Jour., v. 23, p. 246–263.

EL SALVADOR

The Republic of El Salvador, smallest of the mainland American Republics, faces the Pacific side of the Central American isthmus. Except for a narrow coastal plain, El Salvador is largely a dissected upland plateau surmounted by an east-west chain of volcanoes, some of which are active and others intermittently so. Since its establishment as an independent republic in 1829 following the dissolution of a short-lived Federal Republic of Central America, El Salvador has provided strong leadership in the cultural and economic affairs of the region and has maintained a long tradition of friendship with the United States, its principal trading partner.

One of the earlier USGS involvements in overseas bilateral technical assistance was in 1943–44 when A. N. Sayre and G. C. Taylor, Jr., USGS hydrogeologists, were assigned to the Institute of Inter-American Affairs to study critical problems of water supply in El Salvador, as part of the cooperative program of IIAA's Health and Sanitation Division with the Salvadorean Directorate of Sanitation. Mr. Sayre spent 3½ months in El Salvador from June until September 1943 and Mr. Taylor, 7 months from July 1943 to February 1944.

During the course of the fieldwork, geologic and hydrologic studies were made of the water-supply problems of about 35 towns and cities in the republic. Individual reports were prepared both in Spanish and English by Messrs. Sayre and Taylor as well as by Mario Pacheco and Carlos Alemán, Salvadorean engineers, for each of the localities visited and a summary report was published as USGS Water-Supply Paper 1079–D. These reports described the geologic, hydrologic, sanitary, and economic features of existing and potential water supplies and made recommendations for their development or improvement.

Geologic and hydrologic studies were also made along the Pan American Highway in the 290-km stretch across the country from Guatemala to Honduras. About 50 sites were selected for the development of springs or the construction of wells as roadside watering places along the highway for travelers or livestock.

Most of the recommendations made by Messrs. Sayre and Taylor were subsequently put into effect in some 200 public water-supply development projects sponsored by the Directorate of Sanitation during the 1940's and 1950's and with technical assistance from the IIAA, US AID and predecessors, and the Pan-American Health Organization. In 1962, an autonomous agency, the National Administration of

Waterworks and Sewerage (ANDA) was established and as of 1970 planned, financed, constructed, operated and maintained water-supply and sewerage systems for virtually all the cities and towns in the country, or about 25 percent of the total population.

The United Nations also provided large inputs of technical assistance to El Salvador during the 1960's. These included surveys of the geothermal energy resources of active volcanic areas and the groundwater potentials of the San Miguel Valley and the San Salvador metropolitan area for irrigation and municipal water supply.

References

Alemán, Carlos, 1943, Report relative to the present water service of Tonacatepeque, El Salvador: U.S. Geol. Survey open-file rept., 3 p.

Pacheco, Mario, 1943a, A water supply for California, El Salvador: U.S. Geol. Survey open-file rept., 4 p.

——— 1943b, Report concerning the water service of Jocoro, El Salvador: U.S. Geol. Survey open-file rept., 4 p.

——— 1943c, Recommendations for improving the water services of Jucuapa, El Salvador, C. A.: U.S. Geol. Survey open-file rept., 4 p.

——— 1943d, The water service of La Libertad, El Salvador: U.S. Geol. Survey open-file rept., 7 p., 1 fig.

——— 1943e, Memorandum concerning the water supply of Mejicanos, El Salvador, and recommendations for improving it: U.S. Geol. Survey open-file rept., 7 p., 3 figs.

——— 1943f, Report concerning the water supply in Quezaltepeque, El Salvador: U.S. Geol. Survey open-file rept., 7 p., 1 fig.

——— 1943g, A water supply for San Carlos, El Salvador: U.S. Geol. Survey open-file rept., 3 p.

——— 1943h, The municipal water service in San Julian, El Salvador: U.S. Geol. Survey open-file rept., 4 p.

——— 1943i, Report relative to the improvement of the water services of San Vicente, El Salvador: U.S. Geol. Survey open-file rept., 8 p., 1 fig.

——— 1943j, Report relative to the water service in Sensuntepeque, El Salvador: U.S. Geol. Survey open-file rept., 6 p., 1 fig.

——— 1943k, Report concerning the water supply of Villa Delgado, El Salvador, and recommendations for improving it: U.S. Geol. Survey open-file rept., 8 p.

Sayre, A. N., 1943a, Memorandum regarding an improved water supply for the city of Cojutepeque, El Salvador: U.S. Geol. Survey open-file rept., 5 p.

——— 1943b, Memorandum concerning the possibility of obtaining a suitable water supply at a proposed rastro at Prusia, El Salvador: U.S. Geol. Survey open-file rept., 3 p.

——— 1943d, Memorandum concerning the water supply at Zacatecoluca, El Salvador: U.S. Geol. Survey open-file rept., 4 p.

Sayre, A. N., and Taylor, G. C., Jr., 1943, Water supplies at Santa Rosa, El Salvador: U.S. Geol. Survey open-file rept., 4 p.

——— 1943c, Memorandum regarding the water supply of Usulutan, El Salvador: N.S. Geol. Survey open-file rept., 4 p.

——— 1951, Ground-water resources of the Republic of El Salvador, Central America: U.S. Geol. Survey Water-Supply Paper 1079D, p. 155–225, 3 pls., 7 figs.

Taylor, G. C., Jr., 1943a, Municipal water supply a Ahuachapán El Salvador: U.S. Geol. Survey open-file rept., 5 p.

——— 1943b, Water supply of Antiguo Cuscatlán, El Salvador: U.S. Geol. Survey open-file rept., 4 p.

——— 1943c, An improved municipal water supply at Armenia, El Salvador: U.S. Geol. Survey open-file rept., 5 p.

——— 1943d, Municipal water supply at Atiquizaya, El Salvador: U.S. Geol. Survey open-file rept., 6 p.

——— 1943e, An improved water supply for Chapeltique, El Salvador: U.S. Geol. Survey open-file rept., 3 p.

——— 1943f, A water supply for El Chilamatal, El Salvador: U.S. Geol. Survey open-file rept., 6 p.

——— 1943g, A water supply for El Refugio, El Salvador: U.S. Geol. Survey open-file rept., 4 p.

——— 1943h, Water Supply at El Triunfo, El Salvador: U.S. Geol. Survey open-file rept., 6 p., 5 figs.

——— 1943i, Conditions of water supply at Guadaloupe, El Salvador: U.S. Geol. Survey open-file rept., 4 p., 1 fig.

——— 1943j, Recommendations for improving water supplies at Jiquilisco, El Salvador: U.S. Geol. Survey open-file rept., 4 p.

——— 1943k, A water supply at Nevua Granda, El Salvador: U.S. Geol. Survey open-file rept., 4 p.

——— 1943l, A water supply at Panchimalco, El Salvador: U.S. Geol. Survey open-file rept., 4 p., 1 fig.

——— 1943m, The municipal water supply at San Francisco Gotera, El Salvador: U.S. Geol. Survey open-file rept., 5 p.

——— 1943n, An improved water supply for San Martin, El Salvador: U.S. Geol. Survey open-file rept., 6 p., 1 fig.

——— 1943o, Municipal water supply at Santa Tecla, El Salvador, C. A.: U.S. Geol. Survey open-file rept., 12 p.

——— 1943p, Water supplies at Tejutepeque, El Salvador: U.S. Geol. Survey open-file rept., 4 p., 2 figs.

——— 1943q, Water supply for Tepetitan, El Salvador: U.S. Geol. Survey open-file rept., 4 p., 1 fig.

——— 1943r, Water Supply at Verapaz, El Salvador: U.S. Geol. Survey open-file rept., 4 p., 1 fig.

——— 1944a, Condition of ground-water occurrence in the city of San Salvador, El Salvador, C. A.: U.S. Geol. Survey open-file rept., 4 p.

——— 1944b, Gravity water supplies of San Salvador, El Salvador: U.S. Geol. Survey open-file rept., 12 p.

GUYANA

Guyana, situated on the northeast coast of South America, includes an inland forested plateau covering some 85 percent of the country and a coastal plain 15 to 65 km wide facing the ocean. Cultivation of sugar cane on the coastal plain provides the agrarian base of the country, and sugar accounts for about one-third of the country's exports. The United States has maintained a modest technical assistance program in Guyana since 1954, and the USGS participated in water-resources studies on one occasion in 1957.

Following observed declines in pressure heads and resulting concern over possible failure of the artesian water supply in the coastal zone of Guyana, the Government of Guyana requested US ICA in late 1956 to porvide the services of a U.S. expert to evaluate the problem. Accordingly, G. F. Worts, Jr., USGS hydrogeologist, was assigned from February until April 1957 to make a reconnaissance of the ground-water conditions in the coastal artesian basin and to design a long-term program of ground-water investigations directed toward conservation and management of the artesian basin. During his stay, Mr. Worts worked closely with scientists and engineers of the Guyanan Geological Survey, the Drainage and Irrigation Department, the Transport and Harbours Department, the Meteorological Laboratory, and the Pure Water Supply Scheme.

His report, published in 1958 as Guyanan Geological Survey Bulletin 31, described the general ground-water geology and hydrology of the coastal artesian basin, including related surface-water and water-quality features. Mr. Worts concluded: (1) that the decline in head and flow of the artesian wells was due to mutual interference and not to depletion of the supply, (2) that decline in head along the coast could result in seawater intrusion in the future, and (3) that pumping from wells near the coast is undesirable because the threat of seawater intrusion would be increased. The report also presents detailed recommendations for scope of work and for organization and interdepartmental cooperation in ground-water investigations—including collection, recording, and compilation of basic data; equipment needs; aquifer testing; water analyses; well logging; and surficial and subsurface geologic studies.

Since this work, the Guyana Government with technical and economic assistance from US AID, the U.N. agencies, and private U.S. engineering consultants, has pursued effectively the goals recommended by Mr. Worts. As a result, the ground-water resources of Guyana's coastal plain, where some 90 percent of the population is concentrated, have since been carefully monitored and managed for rural irrigation and industrial and public water supply.

References

Worts, G. F., Jr., 1958, A brief appraisal of ground-water conditions and proposed program for water resources investigations in the coastal artesian basin of Guyana, [British Guiana], South America: Guyana Geol. Survey Bull. 31, 52 p., 1 pl.

——— 1963, A brief appraisal of ground-water conditions in the coastal artesian basin of Guyana, [British Guiana], South America: U.S. Geol. Survey Water-Supply Paper 1663–B, 1 pl, 44 p.

HAITI

The Republic of Haiti, second oldest independent nation in the Western Hemisphere, gained its independence from France in 1804. Haiti occupies the western third of the island of Hispaniola in the Caribbean Sea. The country is largely mountainous with semiarid conditions prevailing in the lowland arable areas. Irrigation in these areas, the so-called "tradewind deserts," has been practiced, both from stream diversions and from wells since French colonial times, mainly for cultivation of bananas, sisal, and sugarcane.

A bilateral agreement for economic aid and technical assistance was concluded in 1919 between the U.S. Department of State and the Government of Haiti. As a part of the technical assistance program a four-man USGS team was assigned to Haiti and completed between October 1920 and April 1921 a nationwide reconnaissance of the geology and the mineral and ground-water resources. A comprehensive report on this reconnaissance was published in English and French in 1924 by the Haitian Geological Survey, Direction Generale des Travaux Publics (DGTP). In this report, J. S. Brown, USGS hydrogeologist, described the ground-water resources of some 15 arid lowland plains and valleys and evaluated their extant and potential development for irrigation and public water supply.

During October–November 1921, N. C. Grover, then Chief Hydraulic Engineer of the USGS, made a field reconnaissance of the surface-water resources of Haiti to determine requirements for a countrywide stream-gaging network. Based on recommendations in his report of January 1922, a Hydrographic Division was established in August 1922 with a technical staff of engineers and 24 gage observers. Also, a countrywide program of regular streamflow measurements began at some 81 regular and partial-record gaging stations, distributed in 10 hydrographic districts. The measurements were continued systematically, and the results were published from 1922 until 1936 in an annual series of 14 Hydrographic Bulletins released by the DGTP. By the end of 1936, some 8,995 individual streamflow measurements had been made. Since 1936, publication of streamflow records has languished, owing chiefly to lack of financial support. Nevertheless, actual streamflow measurements have been continued with some interruptions, for the past 35 years by the

Service des Eaux et Forêts, and unpublished data have been retained in the files of the DGTP.

After World War II and before 1963, the United States provided $105 million of technical assistance and economic aid of all types to the Government of Haiti. As part of this program, the Food Supply Division of the Institute of Inter-American Affairs in mid-1948 requested the USGS to provide the short-term services of a hydrogeologist (1) to evaluate ground-water conditions in certain of the arid lowlands, (2) to determine the feasibility of extending ground-water development for irrigation and other purposes, and (3) to define suitable sites for drilling production wells to irrigate pilot agricultural projects. G. C. Taylor, Jr., USGS hydrogeologist, was assigned to the work between September 1948 and March 1949 and was assisted by Remy C. Lemoine, Haitian engineer-geologist of the Service Cooperatif Interamericaine de la Production Agricole (SCIPA). Together Messrs. Taylor and Lemoine studied the Cul-de-Sac, Gonaïves, Arcahaie, and Moustiques Plains; the Jacmel-Meyer Bench; and the Forêt des Pins region and prepared six reports describing their findings and recommendations for each of these areas. During the 1950's, Mr. Lemoine continued and participated in this work and, together with US TCA, FOA, ICA, and AID engineers, guided several ground-water exploration and development projects in Haiti.

In response to a request from the Government of Haiti to US ICA, H. A. Waite, USGS hydrogeologist, was assigned during August–September 1959 to undertake a reconnaissance of: (1) the sources of water supply for the city of Port-au-Prince and (2) the water supplies of 12 towns and villages in the Department du Nord and to recommend ways of improving, extending, and increasing these supplies. During his stay in Haiti, Mr. Waite worked closely with engineers of the Haitian Service Hidraulique, Department des Travaux Publics; of the US ICA; of Metcalf and Eddy, consultants to U.S. ICA and the Government of Haiti; and of the Haitian-American Sugar Co. In his report of August 1960, Mr. Waite recommended a comprehensive ground-water investigation in the Plaine du Nord; the assignment of a U.S. ground-water specialist to Haiti for a 2-year period; and the training in the United States of two or three Haitian technicians for a 6-months study of ground-water problems, procedures, and investigations. Most of Mr. Waite's recommendations for improving the water supplies of the 12 towns and villages in the Department du Nord involved captation of springs and delivery of the water by gravity pipeline to public fountains or other water services. For the city of Port-au-Prince, he suggested importation of water from the Rivière Froide by extension of the Diquini Tunnel, appropriation and addition of new springs to the existing gravity system, and drilling of wells for municipal supply in the Cul-de-Sac Plain near Port-au-Prince.

Following on Mr. Waite's recommendations, John Logan, a US AID hydrogeologist, was assigned to Haiti to carry out ground-water investigations throughout the country and to train Haitian technicians in the field and office methodology. During his stay (October 1960–February 1963) in Haiti, Mr. Logan worked closely with Mr. Lemoine. Together, they compiled a report released in August 1962, which describes the geologic and hydraulic characteristics of some 100 exploratory and production wells put down during the 1950's, largely in the Cul-de-Sac, Archaie, and Gonaïves Plains and the Plaine du Nord near Cap Haïtien.

The US AID program in Haiti terminated in August 1963, and since then and as of 1970, virtually all U.S. assistance has been channeled through multilateral programs.

References

Taylor, G. C., Jr., 1949a, Ground-water studies in Haiti: *in* Progress in Agriculture, Inst. Inter-Am. Affairs, p. 1–4, 2 figs.

——— 1949b, Ground-water conditions in the Plaine des Moustiques, Haiti: U.S. Geol. Survey open-file rept., 5 p., 1 fig.

——— 1949c, Ground-water reconnaissance of the Jacmel-Meyer bench, Haiti: U.S. Geol. Survey open-file rept., 13 p., 1 fig.

Taylor, G. C., Jr., and Lemoine, R. C., 1949a, Les rivières et les sources de la Plaine du Cul-de-Sac; Les eaux souterraines dans la Plaine des Gonaives, Haiti: Soc. Haitienne Histoire et Geographic Rev., v. 20, no. 75, p. 1–32.

——— 1949b, Ground water in the Arcahaie plain Haiti: U.S. Geol. Survey open-file rept., 17 p., 1 fig.

——— 1949c, Ground water in the Cul-de-Sac plain, Haiti: U.S. Geol. Survey open-file rept., 1 pl., 60 p.

——— 1949d, Ground water in the Gonaives plain, Haiti: U.S. Geol. Survey open-file rept., 23 p., 1 fig.

——— 1949e, Ground-water reconnaissance in the Pine Forest region, Haiti: U.S. Geol. Survey open-file rept., 6 p.

——— 1950, Ground-water geology of the Gonaives plain, Haiti: Econ. Geology, v. 45, no. 2, 127–131.

——— 1952, Eaux souterraines dans la Plaine de l'Archaie, Haiti: Soc. Haitienne Histoire et Geographie Rev., v. 23, no. 86, p. 46–57.

Waite, H. A., 1960, Reconnaissance investigations of public water supplies of Port-au-Prince and in 12 villages in the Department du Nord, Haiti: U.S. Geol. Survey open-file rept., 105 p., 3 figs.

NICARAGUA

Nicaragua, largest of the Central American Republics, established its independence in 1838 after the break-up of a short-lived Federal Republic of Central America. The United States has provided continuous inputs of bilateral technical assistance and economic aid to Nicaragua during and since World War II. Between 1960 and 1968 this aid totalled $138 million.

Perhaps the earliest recorded involvement of the USGS in Nicaragua was the work of A. P. Davis, USGS hydrologist, who was attached to the Nicaraguan Canal Commission in 1897–98. In the commission's report of 1898, Mr. Davis described observations on the fluctuations of Lakes Nicaragua and Managua as well as the hydrology of the Río San Juan along a proposed trajectory of a transisthmian canal.

In August 1943 and at the request of the Nicaraguan Dirección General de Sanidad to the Division of Health and Sanitation, Institute of Inter-American Affairs, A. N. Sayre and G. C. Taylor, Jr., USGS hydrogeologists, were assigned for 2 weeks to evaluate the water-supply problems of the city of Managua and of Las Sierras plateau to the southwest. Mr. Sayre in his report of August 1943 reviewed the economic, geologic, hydrologic, and sanitary problems of the extant (1943) municipal water supplies from a pumping station on Lake Asososca and from private wells and recommended improvements and alternatives, including possible pumping from an infiltration gallery adjacent to Lake Tiscapa and five or six properly spaced and constructed wells 150 m or more deep in the environs of the city. Mr. Taylor in a separate report, also of August 1943, reviewed the water-supply problems and ground-water conditions in the volcanic rocks of Las Sierras plateau southwest of Managua, particularly near Diriamba, Jinotepe, and Masaya, and recommended exploratory drilling and ground-water development in the vicinity of Casa Colorado and elsewhere on the plateau to provide needed municipal, domestic, and stock water supplies.

At the request of US ICA/Managua, S. L. Schoff, USGS hydrogeologist, was assigned for 19 days in September 1956 to evaluate the results of exploratory drilling in 1954–55 at the La Calera Agricultural Experiment Farm near Managua. Mr. Schoff concluded in his report of October 1956 that the aquifers in the vicinity of the farm were sufficiently productive to provide water for irrigation but that carefully drilled and properly screened wells would be needed to extract the water.

Most of the recommendations of Messrs. Sayre, Taylor, and Schoff were subsequently put into effect in the progress of the Nicaraguan government's water-supply development programs. More recently these recommendations were included in a yearlong comprehensive feasibility study of water-supply development needs for the Managua area completed in January 1964 by Hazen and Sawyer, consulting engineers. Another detailed feasibility study for water supply and sewerage for 10 towns in western Nicaragua was completed in November 1969 by Gilbert Associates, consulting engineers. This work included the cities of Masaya, Jinotepe, and Diriamba.

Beginning in 1966, areal ground-water investigations in western Nicaragua were undertaken by a private concern, the Development and Resources Corp., under a US AID development loan for national natural resources surveys. Since 1967 the United Nations with United Nations Development Programme financial support also has sponsored ground-water investigations in selected areas of western Nicaragua.

References

Sayre, A. N., 1943, Memorandum concerning proposed water-supply development at Lake Tiscapa, Managua, Nicaragua: U.S. Geol. Survey open-file rept., 9 p.

Schoff, S. L., 1956a, Ground water for irrigation at La Calera, Nicaragua: U.S. Geol. Survey open-file rept., 7 p.

——— 1956b, Ground-water data, Nicaragua: U.S. Geol. Survey open-file rept., 25 p., 4 illus., 2 maps.

Taylor, G. C., Jr., 1943, Conditions of ground water on the plateau of La Sierras, Nicaragua: U.S. Geol. Survey open-file rept., 3 p.

PANAMÁ

The Republic of Panamá, occupying the narrowest part of the mountainous isthmus between North and South America, gained its independence from Colombia in 1903. Since completion of the Panamá Canal in 1915, Panamá's economy has been closely tied to servicing the transit trade through the canal. Also, with the United States as its principal trading partner, Panamá has received U.S. bilateral aid for more than 50 years. During 1961–68, U.S. aid amounted to about $110 million. As part of the U.S. aid program the USGS provided short-term technical assistance to the Panamanian government on four occasions—1949, 1962, and 1964–65.

As part of a cooperative program with the U.S. Department of Agriculture, the Panamanian Ministry of Agriculture, Commerce, and Industries in early 1949 requested the short-term services of a U.S. specialist to evaluate ways of developing and improving water supplies for livestock in the range-

lands of central Panamá. G. C. Taylor, Jr., USGS hydrogeologist, was assigned to the work and during April and May 1949 completed a reconnaissance of ground-water conditions of Herrera Province and adjoining areas in Coclé, Los Santos, and Veraguas Provinces, all in the northern part of the Azuero Peninsula. His report of May 1949 described the general hydrogeology of the volcanic rocks of the region, occurrence of ground water, characteristics of existing wells, and the then-current ground-water problems. He also pointed out that the water-bearing rocks, which are largely of volcanic origin, will generally provide yields of 0.1 to 1.0 l/s (litres per second) (sufficient for livestock) to 152- to 203-mm (millimetre) wells 30 to 60 m deep in most of the region, but that total well failures, because of geologic factors, could be anticipated with about a 5 percent frequency. Moreover, he indicated that other failures could result from careless drilling practices or poor well construction.

In response to a request from the Panamanian Instituto de Recursos Hidraúlicos y Electrificación (IRHE) to US AID Panamá, J. T. Callahan, USGS hydrogeologist, was assigned to Panamá in February 1962 to evaluate the needs for a long-term program of ground-water investigations focused particularly on the water-short central region and the Azuero Peninsula. Mr. Callahan's report of April 1962 recommended, as a first measure, a 2-year pilot study on the Azuero Peninsula, including needs for coordination among Panamanian government agencies; exploratory drilling; geologic and hydrologic field activities; personnel training; and scope, methods, and timing of study.

In 1963, Mr. Callahan's proposals for ground-water investigations were incorporated in a comprehensive 5-year "Cadastro Rural de Tierras y Aquas de Panamá" implemented by a private contractual consortium (CATAPAN), with US AID loan funds and with counterpart participation of several Panamanian government agencies, including IRHE. As part of this program, US AID/Panamá in mid-1964 requested the short-term services of a USGS specialist in ground-water geology and hydrology. To carry out this work, R. J. Dingman, USGS hydrogeologist, was assigned to Panamá for a 3-month period (October 1964–January 1965) to train five IRHE geologists and engineers in the operation of an electric logger; interpretations of resistance, self-potential, and gamma ray logs; field methods of collecting ground data; and identification of common rock types and well cuttings. He also identified areas of moderate to large ground-water potential near La Flora and Las Flores in the Azuero Peninsula. His report of February 1965 recommended a 5-year program of ground-water field investigations, participant training, and institutional development centered in the Panamanian Department of Mines. Although not all the administrative recommendations of Messrs. Callahan and Dingman were implemented as originally proposed, many of the technical recommendations have been effected, notably by F. L. Doyle, CATAPAN hydrogeologist, as part of the ground-water phase of the Cadastro Rural, which was completed in 1968.

At the invitation of the Secretary, Permanent Planning Commission for Water of IRHE and under the auspices of US AID, H. E. Thomas, USGS hydrologist, was assigned in July–August 1962 to consult with and assist Panamanian officials in hydrologic and legal problems related to national water law. During his stay in Panamá, Mr. Thomas developed a Proposed National Water Code for inclusion in a new Agrarian Code. A few years later through two governmental decrees of September and October 1966, respectively, all water uses and rights were brought under governmental supervision, and an inter-agency National Water Commission was established to control and protect all the national water resources.

Reference

Taylor, G. C., Jr., 1949, Ground water in Herrera Province and adjoining areas in Coclé, Los Santos, and Veraguas Provinces, Panamá: U.S. Geol. Survey open-file rept., 20 p., 1 pl., 2 figs.

PERU

Legendary home of the Inca empire and later seat at Lima of the viceroyalty of Spanish America, Peru has filled a centerstage position in the cultural and political affairs of South America for more than 400 years. Occupying the western bulge of the continent, Peru has climatic regimens ranging from the cool deserts of the Pacific coastal zone to the high barren páramos of the Andes and the tropical rain forests of the upper Amazon basin in the trans-Andean region. Because of perverse geography and other factors, Peru had suffered for many decades from economic stagnation. Since World War II, however, the Government of Peru with the help of international donors has made strong efforts to modernize its institutions commensurate with the demands of the times. In support of Peru's efforts to raise national living standards and to strengthen the economy, the United States provided some $619 million of bilateral aid between 1945 and 1969.

As a part of U.S. aid to Peru during the 1950's, the Peruvian Comisión de Colaboración and US FOA/Lima sponsored a long-term program of technical assistance in minerals and ground-water investigations with USGS participation. In this program, S. L. Schoff, USGS hydrogeologist, was assigned in February 1955 to carry out ground-water evaluations and appraisals of critical areas and problems throughout the arid coastal region of Peru. Mr. Schoff's assignment in Peru continued until July 1959, when he returned to the USGS domestic program. Shortly after his arrival, Juan L. Sayán M., Peruvian engineer-geologist with the Servicio Cooperativo Interamericano de Irrigación, Vías de Comunicación e Industrias (SCIIVCI), was assigned to work with Mr. Schoff and continued in this capacity until Mr. Schoff's departure from Peru.

One of the first activities of Mr. Schoff and Engineer Sayán was a 3-months' ground-water survey of the Lima area undertaken as part of a "Study Commission for Improvement of the Distribution System for the Water Supply of Lima" sponsored by the Peruvian Ministry of Development and Public Works. Their report, included as an appendix in the general report of the Study Commission, was released in January 1956. The Schoff-Sayán report described the general geology and hydrology of the Río Rimac basin and the ground-water potential of the valley fill and estimated withdrawals from wells and infiltration galleries at approximately 160,000 m^3/d (cubic metres per day).

Together with Engineer Sayán, Mr. Schoff also began in September 1955 a comprehensive investigation of the ground-water geology and hydrology of the Lambayeque Valley in northern Peru which was continued intermittently until April 1958. A report on the investigation, first released in 1959 and later formally published as USGS Water-Supply Paper 1663–F, describes in detail the hydrogeology and the occurrence, chemical quality, temperature, and the then-existent as well as potential development of the ground-water resources of the valley.

A severe drought that affected southern Peru in 1955–56 gave compelling impetus to the need for comprehensive planning in the economic development of the region. Accordingly, and by Presidential decree, an inter-ministerial committee was formed in the Government of Peru to organize a "Plan Regional para el Desarrollo del Sur del Perú (PRDSP)" (Regional Plan for the Development of Southern Peru) and to mount with the technical and financial assistance of US ICA a study team of some 60 national and foreign experts charged with field investigations, research, and evaluations required for the plan. As a phase of this work, Mr. Schoff and Engineer Sayán completed between August and November 1958 a general reconnaissance of ground-water conditions in the seven provinces of southern Peru. Their findings were published in 1959 as volume 3 of the general 30-volume PRDSP report. They described the general hydrogeology of the region and concluded that ground water in some areas, such as near Tacna and in the lower part of the Moquequa valley, may be overdeveloped but that other areas, such as the valleys of the Majes, Tambo, and lower Sama with good potential had not been fully developed. They also pointed up the need for conjunctive use and management of both surface water and ground water in the extensive irrigated area near Arequipa.

During his stay in Peru, Mr. Schoff also completed brief ground-water studies at La Granja San Jorge, near Huancayo, in the Pampa de La Joya, at Ilo, in the Pampa de Sihaus, in the Tacna Valley, at Matarani and Mollendo, in the Pampa de Ñoco, near Puno, and near Tumbes. The results of these studies were released in 10 USG open-file reports.

Since 1960 the ground-water investigations and studies of Mr. Schoff and Engineer Sayán have provided an important and useful base for further reconnaissance under UNESCO's technical assistance program and for development-oriented feasibility studies of the Inter-American Development Bank (IADB) and the U.N. Food and Agriculture Organization (FAO), as well as in regional development planning of the Government of Peru.

References

Schoff, S. L., 1955a, Cuanta aqua tiene el Peru: First Natl. Geol. Cong. Peru, November 1955, 14 p.

——— 1955b, First drilled well at La Granja San Jorge, Coronel Portillo Province, Peru: U.S. Geol. Survey open-file rept., 7 p.

——— 1955c, Ground water near Huancayo, Peru: U.S. Geol. Survey open-file rept., 9 p.

——— 1955d, Ground water for irrigation of the Pampa de La Joya, Arequipa Department, Peru: U.S. Geol. Survey open-file rept., 9 p.

——— 1955e, Ground water for irrigation of the Pampa de Majes, Arequipa Department, Peru: U.S. Geol. Survey open-file rept., 9 p.

——— 1955f, Ground water for irrigation of the Pampa de Sihuas, Arequipa Department, Peru: U.S. Geol. Survey open-file rept., 9 p.

——— 1955g, Ground water at Ilo, Mariscal Nieto Province, Peru: U.S. Geol. Survey open-file rept., 3 p.

——— 1955h, Ground water at Matarani and Mollendo, Arequipa Department, Peru: U.S. Geol. Survey open-file rept., 2 p.