January 1970

Water management research in arid and sub-humid lands of the less developed countries: Second annual progress report

Utah Water Research Laboratory

WATER MANAGEMENT RESEARCH

IN

ARID AND SUB-HUMID LANDS

OF THE

LESS DEVELOPED COUNTRIES

Contract AID/csd-2167

Second Annual Progress Report
November 1, 1969 - October 31, 1970

to

The United States Agency for
International Development

prepared by

The Department of Agricultural and

Irrigation Engineering

Utah Water Research Laboratory
College of Engineering
Utah State University
Logan, Utah 84321

USA

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WATER MANAGEMENT RESEARCH IN ARID AND SUB-HUMID LANDS OF THE LESS DEVELOPED COUNTRIES

Background

USAID Contract csd-2167 with Utah State University provides funds for Water Management Research in Less Developed Countries for the purpose of increasing the food supply in those areas. The contract was signed on June 28, 1968, and funded for an initial period of 21 months.

By mutual agreement between AID and USU officials and in consultation with the other members of the CUSUSWASH* consortium, USU's efforts are focused principally on the problems of on-farm water management, and the field work is being undertaken primarily in Latin America.

Basis for Developing a Plan of Work

In order to carry out effective research in Latin America, strategies had to be conceived which would not only ensure that significant research was carried out with the resources provided but that the results would be made available in such a way that they could and would be utilized to increase food production. During the first contract period, three criteria for success were identified:

1. The research undertaken would be within the range of competence of USU staff.
2. The research must be seen as useful by:
   a. USAID mission officials.
   b. National Development and Agricultural Research Agency officials.
   c. USU staff.
3. National Development agencies must be involved to insure that:
   a. They internalize the work, or that they become comitted to its success.
   b. They have meaningful learning opportunities through working with USU counterparts.
   c. Adequate logistical support is provided.
   d. The incentives are strengthened among the Latin American researchers to build upon work initiated through the contract.

*Council of United States Universities for Soil and Water Development in Arid and Sub-Humid Areas.

Since data collection and research in agricultural production is a well established activity in Latin America, USU's program must be coordinated with existing national research programs. This is an important "constraint," the working within already established goals or objectives of the various AID missions and the national research and development agencies. Without going into considerable detail on the many meetings and exchanges of correspondence, it is not possible to give a clear picture of just why the program has developed the way it has.

The sub-programs underway and proposed are the most feasible combinations which, given the constraints and objectives already mentioned, are in our opinion the most likely to maximize the desired results.

A problem frequently discussed but not yet completely resolved is whether to try to concentrate our efforts in two or three countries or spread out. Full time staff are planned for Chile, El Salvador, Colombia, Ecuador, and Brazil. Our budget proposal for 1971-72 includes one additional full time professional field man who will be located in Colombia.

The principal reason for our involvement in these countries is that their AID missions viewed the contract objectives as complimenting their own mission objectives and were successful in arranging satisfactory working agreements with the host country agencies. USU has tried to be sensitive to the needs and opportunities as identified by the local AID mission personnel. Unless local geographical, political or logistical support problems make the work in any of the countries especially difficult or unproductive we will continue to respond to needs as identified by AID missions within the objectives of the contract and the budget restrictions.

Organization, Administration, and Logistical Support

Due to a reorganization within the University it was necessary to make an administrative change. Bruce H. Anderson, Project Field Director, became Director of International Programs, a University Department which gives some logistical and advisory support to the contract but not supervisory support.

Byron C. Palmer, who returned in August from a three-year University assignment in Venezuela and Colombia, was appointed Field Director.

Kern Stutler was engaged in July and sent to Chile to work with Don Kidman who has been there since September 1969. Morris Whitaker, an agricultural economist, was employed full time as of October 1, 1970, on the collection and evaluation of economic data, especially that pertaining to Latin American agricultural production.

George Hargreaves, a well-known hydrologic researcher, joined the staff in August 1970.

Other staff assigned to the program are listed in Appendix A.

Plan of Work

It is assumed that the reader has access to the first Annual Progress Report covering the period June 1968 to March 1970 and the plan of work for April 1, 1970 to March 31, 1971. Eight sub-programs were detailed in those publications.

Restated briefly they are:

PO-1: To determine the irrigation interactions with crop varieties, plant populations and fertilizers for optimum production of crops in the wet-dry areas of Latin America.

PO-2: To prepare and publish technical bulletins on evapotranspiration and water requirements for Latin America on a country and/or regional basis.

PO-3: To determine more specifically the extent and nature of the drainage and salinity problems in Latin America and to find solutions to these problems, especially in the high water table areas.

PO-4: To determine the effect of water management practices on crop yields by utilizing available water during the fall, winter, and early spring seasons to fill the root zone soil moisture reservoir; to develop criteria for optimizing the use of available water by matching cropping patterns to the available supply.

PO-5: To assist SUVALE of Brazil in planning and implementing a program of research, training, and demonstration in selected areas of the Sao Francisco River Basin.

PO-6: To assemble, evaluate, and make available pertinent information relative to water rights and customs in Latin America and to prepare a water law digest; to promote and stimulate programs which will safeguard the water resources of Latin America and direct them toward beneficial use in agricultural production.

PO-7: To develop and promote the use of land and water conservation management techniques for beneficial and efficient use of on-farm water for optimum crop production.

PO-8: To evaluate primary and secondary economic benefits and impacts of improved land and water management practices and to suggest optimal farm operator and regional strategies.

PO-9: To develop training and demonstration programs in water management aimed at increasing the capacity of local technicians and institutions to conserve and manage their water resources for optimum production.

On-Campus Activities

There are six major on-campus activities:

1. Project administration.
2. Latin American hydrologic data compilation and analysis.
3. Development of a double mole plow.
4. Development of models for hybrid computer simulation of surface and sub-surface water systems.
5. Compilation and evaluation of economic data from Latin America.
6. Preparation of bibliographies on pertinent research and listing of related Latin American research agencies.

Status of the Work

In general the first 18 months were primarily devoted to the identification of feasible objectives and activities, preparing plans of work and budgets, identifying long and short term field personnel, adjusting work assignments on campus to ensure that manpower would be available, setting up language training programs for staff to be assigned to the field, securing AID mission and host country support, orientation of field staff through the AID program in Washington and the on-campus activities, setting up accounting and reporting procedures, and organizing administrative procedures and staff.

During 1970 the program started moving into the operational phase: production people were recruited and sent out on both long term and short term assignments. Results began to be felt; reports were prepared; host country professionals were working with and learning from USU field staff. Interpersonal and interagency relationships became better defined.

Four major obstacles to the work developed:

1. The Chilean Government changed. AID Washington decided to hold up sending additional resources into the country pending clarification of U.S. relationships with the new Government. Two programmed visits by a staff economist and a soil scientist were indefinitely postponed. A vehicle purchased for shipment to Chile was held in Logan.

2. The Brazil program was delayed by about six months while the AID mission evaluated Brazil's ability to provide the needed logistical support.

3. The Colombian agreement was delayed about six months, as a result of the problem of getting three government agencies plus AID plus USU to agree on the wording.

4. Bolivia was the country initially selected for the resident location of our Water Law Specialist, Dr. David Daines. However, it became too difficult to secure a concensus among the Bolivian national agency officials on his terms of reference, so negotiations with the Ecuadorian Government were opened through the AID mission representatives. These were eventually successful, but this will delay Dr. Daines' departure from August 1970 to January 1971.

Activities in 1971 will mainly be directed toward production, the preparation of reports resulting from field studies, the providing of support to host country professionals who are doing research in the specific subject areas of the contract and the collection of additional data, particularly in the economics sub-programs.

In addition, strategies will be detailed for circulating the results of the work done so that it will be used and a program of evaluation of the activities developed.

Economic Component

Following the planning meetings of last January, the economics portion of Contract AID/csd-2167 was inaugurated through presentation of the proposed work plan to various missions that had expressed some interest. By the time the budget for 1970 was finalized in April, definite mission approval had been received from Bolivia. Tentative approval had been received from Ecuador. Neither Chile nor Colombia were ready even though Chile was the single country which had project engineers on-site. Drs. LeBaron and Wennergren began preparation of Benchmark agricultural and economic data in Bolivia and established a project for a 211D student in Ecuador during May and June.

Benchmark data collection was undertaken in Ecuador during July by one of the students. Dr. Wennergren returned to Bolivia to supervise some experiments in estimating price elasticities for agricultural products in September. By this date any hope of operating in Colombia in the near term was out and the economists began to concentrate on the collected Benchmark data. Dr. Whitaker, a post graduate fellow, was hired to supervise all the economic data reduction work. In December, after review of the 211D student's success in Ecuador, Dr. LeBaron and Dr. Davis spent a few days there to decide whether further work was possible in the absence of any on-site USU engineers or agronomists.

Excluding planning stages, some nine months of actual field work or research effort has been expended on the economics phase. While it is premature to imply much by way of concrete results, some conclusions about future operating policy should be summarized.

1. We should concentrate our limited field resources in situations or areas where the engineering-agronomy phase is accepted or most likely to be accepted.

2. The experience of the 211D student in Ecuador proves that properly prepared and well motivated students can succeed in Latin field work, even on their own.

3. Our best long-run economics contribution, considering the efforts of larger universities, is to concentrate a constant, consistent portion of our efforts on creation and evaluation of basic crop production function estimates (expecially as related to water inputs).

4. Other economics research, that which might be called the demand portion, should concentrate on the "second generation" problems associated with expanded agricultural production in general or with particular agricultural or development projects.

5. In general these conclusions are in harmony with the economics phase basic work plan as originally conceived.

Specific Country Reports

Bolivia: PO-6 - Water Rights, etc. Dr. Daines will be stationed in Ecuador, but part of his time will be spent in Bolivia and other Latin American countries collecting data and upon request, advising the AID mission and the Ministry of Agriculture on Water Law.

PO-7 and PO-8 - Economic Component. Most of our actual field work in estimating demand elasticities has been confined to this country. One of our Ph.D. students already in Bolivia agreed to set up this work. He has established contacts with market officials in all the larger cities and has completed one or two rounds of a continuing survey of monthly price and quantity fluctuations for major farm commodities. A significant amount of data has been collected but a systematic way of getting all the reports on a common price and unit weight basis is only now being finalized. The results of this kind of effort will not materialize very fast. A minimum of two years will probably be required. No direct resources from our 2167 contract have gone into this work since the first of last October. We are attempting to achieve our aims through coordination with the planning division of the Ministry of Economy.

Several Bolivian Ministry of Agricultural personnel have been and continue to be involved in the data collection and demand estimation work we have begun.

During the coming year we anticipate little or no direct 2167 economic involvements in Bolivia. However, we do expect spin-offs from our association with other USU people in that country and other research contracts.

Reports. Progress report covering time series analysis of price, income, and consumption statistics will be prepared.

Brazil: PO-5 - Assistance to SUVALE. An agronomist and an agricultural engineer have been nominated to go to Brazil to work with SUVALE, the Brazilian Development Agency responsible for the vast Sao Francisco Valley in Brazil's northeast. The Memorandum of Agreement, signed on December 10 and 11, 1970, provides for advice and assistance to SUVALE in planning and executing a program in water management research at selected research and demonstration stations in Brazil. A plan of work will be developed as soon as staff arrive at their posting. Details of the agreement are attached as Appendix B.

PO-8 - Economic Impacts. The economics phase will be included only to the degree approved by the USAID mission and local Brazilian authorities. Dr. Morris Whitaker, who speaks Portuguese and has been a Ford Foundation trainee in Brazil, will be a member of any USU economic input. As a consequence of Dr. Whitaker's recent Brazilian experience and the book he is drafting about agricultural labor problems in that nation, we have a comparative advantage in the planned economics phase.

Certain portions of our existing work plan will have to be modified according to the final project agreed to by USU engineers and agronomists. Our first task will be to cooperate in establishing a unified research plan.

One or two trained junior economists will be available for field studies in Brazil during appropriate growing seasons during the latter part of the coming year.

Chile: WG-1 - Irrigation Interactions. A plan of work was developed in the summer of 1969 which is based primarily on corn studies at six locations. An interesting and important feature of this work is the exceptional success our field staff have had in establishing excellent working relationships with the government agency staff, private entrepreneurs, farm laborers, university faculty, and students.

The plan focuses on soil-fertilizer interaction experiments on corn in the area of the city of Las Andes. These variables are combined with a plant population variable using local and imported seed varieties. Two plots have been established on private farms and, with the active colaboration of the Chilean Ministry of Agriculture, four more plots were installed on communal farms, "asentamientos," in the region. Three seasons of experiments are programmed. It is anticipated that this will provide new information on optimum fertilizer applications under various irrigation applications. The reason for the interest in plant populations is that to our knowledge, no studies of corn population densities have been made at this latitude and the availability of the plots and other resources provides an opportunity to compare U.S. experience with central Chilean plant population possibilities.

The team has also been asked to assist in the evaluation of orchard irrigation practices in collaboration with the Ministry's Agricultural Research Service.

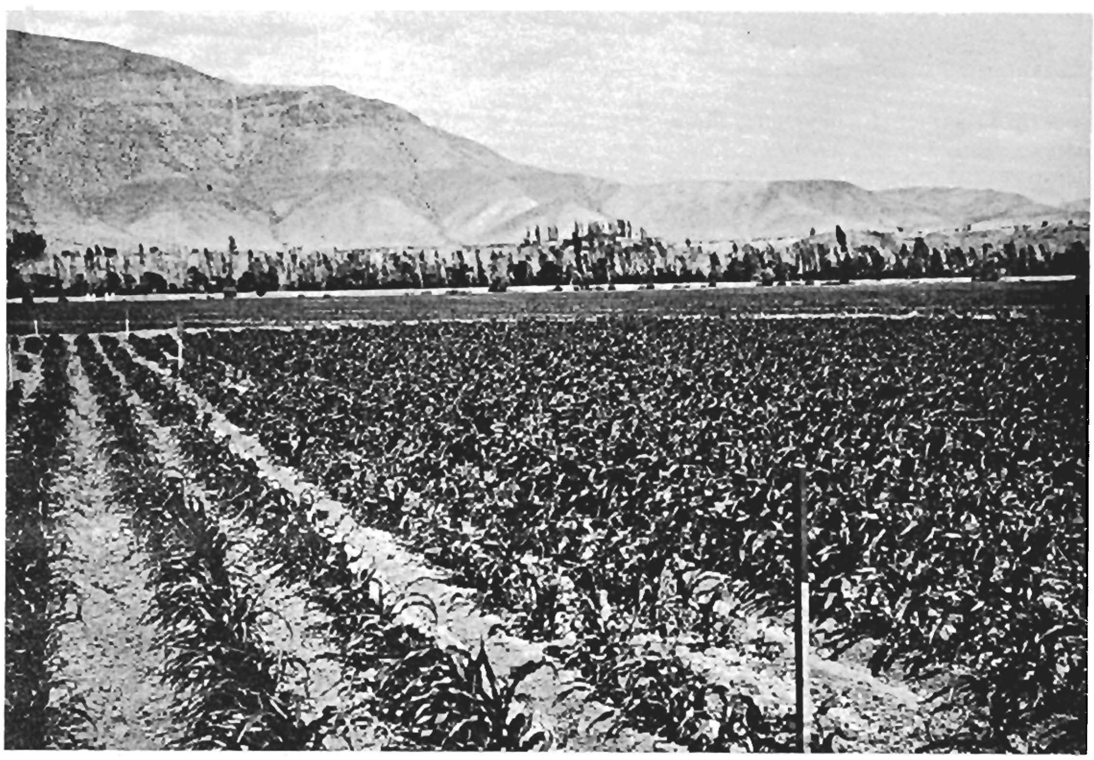
They are working with members of the faculty of the Catholic University of Santiago in designing and presenting field laboratory exercises in irrigation.

Colombia: PO-3 - Drainage and Salinity in Colombia. Our Mr. Darrell Watts worked on the Atlantico-3 project in Northern Colombia from June until mid-September 1969 with follow-up visits in November 1969 and March 1970. A drainage problem was reported on by Darrell Watts in his report entitled "Reclamation Studies on the Light and Medium Textured Soils of Project Atlantico-3, Colombia." This report has indicated the nature of the problem and suggested what needs to be done in order to minimize it. However, part of the solution requires the collection of additional data and a careful interpretation of the data.

It was, therefore, determined that our Dr. Edwin C. Olsen would be assigned for a two-year period to work with the Colombian Agricultural Research Agency (ICA) on the Atlantico-3 project of the Colombian Agrarian Reform Institute (INCORA). Before he could enter the country, an agreement had to be ratified by the Colombian National Planning Agency, ICA, INCORA, the AID mission, and USU. Dr. Olsen was programmed to leave in August. The agreement was delayed in being ratified in Colombia. As a result he will not leave until January. Details of the agreement are included in Appendix C. His initial plan of work is included as Appendix D.

ICA has a new 1,000-acre agricultural research station designated Marconia which started functioning on the Magdalena 1 INCORA project in early 1970. They have asked for a research irrigation agronomist to assist in setting up, monitoring, and evaluating fertilizer, water, and crop interaction research. An acceptable candidate for the position has not been identified yet.

PO-7 - Land and Water Conservation Management Techniques. ICA has expressed the desire to collaborate in research on the use of mole drains. They have agreed to construct a mole plow to USU specifications. As soon as it is built, Professor Bertis Embry will be sent to their research station at Tibaitata near Bogota to assist them in installing the drains and designing a program of evaluation. Backstopping this activity is research currently in



Corn Research Plots - Chile

R. Kern Stutler (L) and Don C. Kidman taking soils samples in the corn plots - Chile.

Utah State University researchers with their Chilean counterparts in the experimental corn plots.

Chilean technician measuring water to corn plots.

Chilean farmer preparing a dust mulch prior to planting corn. This practice, introduced by Don Kidman, reduced irrigation requirements by 20 percent.

Kern Stutler installs a tensiometer in an orchard in Chile.

These trees in the same orchard as those shown above have not received sufficient water because of poorly controlled traditional irrigation methods.

Chilean University students learning how to determine the water holding capacity of the soil.

progress on Utah State University's Drainage Farm at Logan. This activity has been directed toward the development of a plow which produces a reasonably stable drainage conduit at the lowest possible power cost.

Details of the work performed are described in a progress report entitled "Irrigation and Drainage by Mole Systems," written by Komain Unhanand. This work has also resulted in the production of two theses--one entitled "Mole Drainage Construction, Optimum Soil Moisture Content and Corresponding Power Requirement" by a USU graduate student, Kitcha Polparsi, and another entitled "Durability of Double Mole Drains" by USU graduate student Anan Sukwiwat. Copies of these theses are available upon request.

Hydrologic Modeling with Hybrid Computers. Another interesting water conservation management tool--the use of hybrid computers for analysis of water-ground water hydrological systems--has been developed and is in use at USU. Two reports have been prepared which describe the application of the technique to the drainage problem at Atlantico-3 as described by Mr. Watts. These are: "Combined Surface Water-Groundwater Analysis of Hydrological Systems with the aid of the Hybrid Computer" by Morris, Morgan, Wang, and Riley. This study was later refined and a new report, "A Progress Report on Work Accomplished in Computer Simulation" under AID/csd-2167 has just been prepared. This describes methodology for model improvement and makes recommendations on the application of this modeling technique to the management of surface and ground water resources.

PO-8 - Economic Impacts. As yet no in-country economic phase activities have been undertaken. However, some interesting price and quantity data have been collected by one of our colleagues currently stationed in the Atlantico-3 area. We have not tried to analyze it as yet, but we have hopes for its ultimate usefulness.

Now that a USU engineer is on-site at Atlantico-3, we will encourage mission acceptance of the economics phase of 2167. Most of the on-farm portion of the economic phase is especially tailored to situations such as Atlantico-3. Atlantico-3 constitutes a defined project area linked to a definite regional market of substantial size (Barranquilla).

Ecuador: PO-6 - Water Rights. In this country our research is oriented toward the legal and administrative control of water management. Dr. David R. Daines, a

Technicians at USU analyzing hydrologic data from Colombia on hybrid computer.

lawyer, will be stationed in Quito to continue work started during a two-month assignment there in the spring of 1970. Quoting from the Memorandum of Understanding and Agreement between AID, USU, and the Ecuadorian Institute of Hydraulic Resources, "The fundamental objective of the program is the promotion of an increase in efficiency in the utilization of waters, the public security requirements when certain happenings occur, the community uses of waters as well as the functioning of Water Boards; the conduct of litigation or controversies which originate in the country over the uses of water." Data and information on improvements made in these matters from other countries will be employed; moreover, regulations for implementing Article 5 of the Water Law Project will be made. Further details of the agreement are annexed as Appendix E.

Dr. Daines will take with him a very comprehensive microfilmed library on water law. This will be valuable to him and to the program in comparative evaluations of the laws as they apply to various countries. His work will be given a regional orientation. He will be studying water law in Bolivia and Peru, Colombia, and El Salvador, as well as Ecuador. It is expected that the information which he collects and which will ultimately be made available in the form of a water law digest for Latin America will be of direct use to the government officials who are developing and administering water laws in underdeveloped countries, especially those of Latin America.

PO-8 - Economic Benefits and Impacts. The only on-farm economics research undertaken thus far has dealt with irrigated rice operations in Ecuador. The field research was carried out by a Spanish-speaking 211D student in Agricultural Economics. An M.S. thesis should be completed by the end of March. In the absence of experimental data it will be difficult to relate efficiencies in water use to levels of on-farm practices, but this aim of the work plan will not be overlooked.

We plan to devote a small portion of our future resources to Ecuador because we have good relationships established and we believe we can work with agronomists and engineers in the Agricultural Experiment Agency (INEAP). We hope to do more with rice and also begin studies in irrigated oil seeds and cacao.

Studies of Ecuadorian demand for farm products have been confined to analysis of time series data covering prices, incomes and apparent consumption. If we are able to obtain some additional, improved or more extensive data through the efforts of Dr. Daines, and through our other contacts, a publishable report should be forthcoming.

Reports. Progress report of price and income elasticities; progress report on water management in rice production.

El Salvador: PO-1, PO-4, and PO-9. Our Mr. Richard E. Griffin, Civil Enginer, has been in El Salvador since the first of August, 1970. He is working directly with the Irrigation and Drainage Department of the Ministry of Agriculture. Mr. Griffin is actively collaborating with this agency in the development of four research activities. These are:

1. Water fertilizer crop interactions at Zapotitan.
2. Consumptive use studies using lysimeters.
3. Determination of the feasibility of sub-irrigation.
4. Study of alternative drainage methods.

It is likely that the El Salvadorian Government will ask for an additional man to assist in this research program.

The Department of Agriculture is anxious to develop competent extension agents who can directly assist farmers in learning how to use irrigation and drainage techniques. Mr. Griffin is advising them on training methods and also providing some direct education inputs. He is assisting in the setting up of a course on irrigation which will be directed by CIDIAT (Project 213 of the Organization of American States through a contract with Utah State University). Dr. Glenn Stringham, from Utah State University, will, under CIDIAT sponsorship, be directing the course in the third week of February.

It is interesting to note that all of our field staff find frequent opportunities to influence water management research programs through being asked to advise local researchers on their work. This is somewhat difficult to report and measure but is a significant component in our field staff's activities. Appendix F contains the Memorandum of Understanding.

PO-8 - Economic Impacts. As yet no in-country economics phase activities have been undertaken. Mission clearance has been received for Dr. Lynn Davis to plan and establish a complementary economic phase of the seed, fertilizer, water interactions experiment now underway. This will require cooperation in the design of the plot and other field trials to insure maximum benefits for all the required analyses.

We hope to have a full time junior economist, trained, and on the project some time this spring. He will undertake appropriate field surveys. In addition, the necessary Benchmark data collection will be undertaken this spring.

General Observations on the PO-8, or Economics Component Program

In accordance with the approved work plan, the economists on 2167 have completed a substantial bibliography of Latin American agriculture and economic development studies. In addition they also have completed provisional drafts of manuscripts listing numerous Latin American research institutions concerned with land, water, and economic development and a roster of American scientists interested in Latin development programs and policies. At present this list covers mostly economists and agricultural engineers.

General Observations on the PO-2 Program - Evaporation and Water Requirements Studies

Because of the closely interrelated components, this sub-program is reported as an integrated whole rather than on a country-by-country basis.

The principal objectives include the collection, analysis, and evaluation of climatic data for Latin American countries. This includes available evaporation and evapotranspiration data to be used in an analysis of the needs and requirements for irrigation, and in the evaluation of climate as a resource. Analysis and evaluation studies are being prepared on a country-wide country-by-country basis with a view towards providing basic information required for improved water resource development, planning, and for improved irrigation water management.

This activity is mainly financed under the Agency for International Development (Contract AID/csd-2167). The Inter American Geodetic Survey (IAGS), Natural Resource Division, financed through an AID-PASSA contract, made important contributions to the activity during the year. The OAS through their CIDIAT (Centro Interamericano de Desarrollo Integral de Aguas y Tierras) contract with Utah State University has over a period of several years provided funds and assistance for this activity.

Since all Latin American countries do not collect, compile, and publish data in the same manner, and because the data usually required in similar studies may be in short supply or largely nonexistent, considerable research has been required in order to find means of completing studies using available data which will yield acceptable results in the form in which the data have been published. This research has resulted in new equations and methodology that can now be used to complete studies for several countries fairly rapidly.

In the completion of studies, priority has been given to Venezuela, Colombia, and Ecuador. These three countries are, however, fairly large and the assignment is rather complex. Partially for this reason and also because of local demands, it was decided that a report would be first prepared for El Salvador. Data have also been collected on a country-wide coverage basis for Nicaragua and the Dominican Republic. Partial data coverage has been summarized for Peru. A proposed program for data summarization has been submitted to USAID and to government officials in Honduras. Details of status of data collection or report preparation is given in a country-by-country summary in this report.

Irrigation Requirements in Latin American Countries

A technical paper was prepared under the above title for presentation at the meetings of the Association of Engineers and Architects in Israel. This paper will be presented during the week beginning December 14, 1970. The paper describes the geographical area, defines the principal concepts, and presents objectives and procedures, includes the principal equations used and describes some of the principal activities under this project. It is attached as Appendix G.

Evaporation, Evapotranspiration, and Irrigation Requirements for Central America and Panama

Due to the increasing emphasis being placed in this geographical area on irrigation planning, computation of the water balance, and the evaluation of agricultural resources, it was considered desirable that a reliable methodology be developed consistent with the current level of data availability. Data for wind and relative humidity are available only at a limited number of locations. The principal data coverage consists of temperature and precipitation measurements. In order to provide a good working method of computing evaporation and evapotranspiration, a meteorologic study was made of the area. This consisted of plotting wind directions and of using available wind speed and humidity data combined with precipitation and elevation in order to plot lines of equal combined effect of wind and humidity on evaporation and evapotranspiration.

This study is in progress and requires further evaluation of equations presented prior to publication.

Irrigation Requirements and Climatic Evaluation - Venezuela

This study summarizes most of the available evaporation and precipitation data for Venezuela. Class A pan evaporation data are used from 55 stations. Precipitation data for the available period of record are summarized for 148 stations. For these 148 stations, maximum precipitation, minimum precipitation, mean precipitation, dependable precipitation at the 75 percent probability level computed Class A pan evaporation, potential evapotranspiration, the evapotranspiration deficit (potential evapotranspiration minus dependable precipitation) and the moisture availability index (dependable precipitation/potential evapotranspiration) are all summarized by months and annually. These values are averaged in groups by states and by climatic differences. An overall country-wide average is also presented.

The computation of irrigation requirements from the above tabulation is presented. A proposal is given for a graphic and cartographic presentation of an evaluation of climate as a resource. Additional work is in progress principally in connection with Venezuelan precipitation as a thesis project of a Venezuelan graduate student.

Ecuador Study

Precipitation data have been summarized for 110 climatic stations. Complete climatic data have been summarized and averaged for 32 stations. Reliable data are available for temperature and humidity. Wind data are generally available but of probably less reliability. Sunshine hours are measured and published for a few stations. Cloud cover data are published but do not correlate well with other data.

In order to work effectively with the Ecuadorian data, it was necessary to develop new equations.

The extent of Ecuadorian participation in this study has yet to be negotiated. It is hoped, however, that Ecuadorian governmental agencies will undertake the summarization of additional data and the compilation of maps and graphs showing the climatic representation required for the computation of irrigation requirements and for an evaluation of climate.

Climatic Index and Irrigation Requirements for El Salvador

The El Salvador study was prepared at the request of the Instituto Geografico Nacional (IGN) of El Salvador. It was completed in draft and forwarded to the IGN in June of 1970. The study includes a table presenting maximum precipitation, minimum precipitation, mean precipitation, dependable precipitation, computed evaporation, potential evapotranspiration, evapotranspiration deficit, and the moisture availability index by months for 13 climatic stations.

The above relationships are shown in a series of 13 maps showing monthly and annual values and in 13 graphs (one for each climatic station).

Publication of the study in the near future is anticipated. A source of principal delay consisted in the non-availability of plates in-country for the maps and graph reproduction.

A copy of the draft narrative for the study is attached as Appendix C.

Colombia

Precipitation records have been summarized and keypunched for 62 stations. A preliminary analysis of dependable precipitation has been made, and considerable additional data have been collected recently for analysis.

Two studies on evaporation and evapotranspiration in Colombia were recently completed by Guillermo Pardo, a Colombian graduate student, and by R. Kern Stutler. These studies were presented as Master's Degree theses.

Nicaragua

Climatic data have been tabulated for 15 stations and a program was written to compute potential evapotranspiration, dependable precipitation, and evapotranspiration deficits. The equations and methodology have since been improved, however, based largely upon the study of Ecuadorian data, and some revision of the program must be made in order to provide the most desirable output. This can be accomplished within a short period of time provided sufficient demand should develop for a Nicaraguan study.

Peru

Data have been tabulated and placed on computer cards for 25 climatic stations. Some review of these data will be required prior to use in a water management study. More complete and closer personal contact with the agencies collecting and using the data in water management and resource development studies is considered prerequisite to a further work on a study for Peru. It is hoped that such a study can be undertaken.

Dominican Republic

Climatic data were tabulated for 40 stations. Some of these data included Class A pan evaporation. Some preliminary analysis was furnished the USAID mission by the Inter American Geodetic Survey (IAGS) relative to potential evapotranspiration and irrigation requirements. Data on cards are available so that a fairly complete country-wide study can be carried out should there be a need for or requirement for such a study.

Chile

Juan Tosso, a graduate from Chile, is collecting, tabulating, and keypunching climatic data in anticipation of using these data for study of irrigation requirements for Chile presented as a Master's thesis.

Honduras

The USAID mission is studying a proposal that will provide for the collection and compilation of data and for the completion of a study. It is proposed that the computer work and tabulation be carried out at Utah State University and that the maps, graphs, and final report be compiled in Honduras and printed by the agencies participating in the study.

APPENDIX A

PROFESSIONAL AND TECHNICAL STAFF COMMITMENTS TO CONTRACT DURING FISCAL 1970-71

Name	Specialty	Level of Effort mo/yr
A. Alvin Bishop	Project Director	4
Byron C. Palmer	Project Field Director	6
Howard Peterson	Irrigated Soils	3
Lloyd H. Austin	Irrig. Engineer	12
Richard E. Griffin	Irrig. Engineer - El Salvador	12
R. John Hanks	Soil Science	1
George H. Hargreaves	Civil Engineer	12
Jerald E. Christiansen	Civil Engineer	12
Richard Conn	Hydrologist - Technician	12
Edwin C. Olsen	Civil Engineer - Colombia	12
Leon Huber	Computer Specialist	1
J. Paul Riley	Systems Engineer	3
Darryl Watts	Civil Eng. - Drainage	3
Don Kidman	Agronomist - Irrig. - Chile	12
Kern Stuttler	Civil Eng. Irrig. - Chile	12
David R. Daines	Lawyer - Water Rights Ecuador	12
Bertis Embry	Civil Eng. - Drainage	4
Khalilullah Kamandy	Drainage Technician	6
Komain Unhanand	Civil Eng. - Drainage	4
Percy Aitken	Economics Technician	4
Allan LeBaron	Economist	4
David W. James	Soil Chemistry	2
Morris D. Whitaker	Ag. Economist	12
Boyd Wennergren	Economist	3
Total level of effort		167
		or 14 man years / year

APPENDIX B

WATER MANAGEMENT RESEARCH

Memorandum of Understanding and Agreement

Brazil

A. Introduction

This memorandum will outline in general terms the working relationship of Utah State University with SUVALE of the Ministry of Interior, Brazil, and the USAID Mission to Brazil. In conformity with USAID Contract AID/csd-2167, Utah State University, with the approval of USAID/Brazil, will cooperate in water management research program with SUVALE. The University will provide services as outlined in this memorandum which will complement the efforts of the U.S. Assistance team which is provided under Loan No. 512-L-054.

B. Purpose

The purpose of this agreement is to provide advice and assistance to SUVALE in planning and executing a program in water management research at selected research and demonstration stations in Brazil. The data and information obtained will be used in the evaluation of studies (including feasibility studies).

The research program will:

(a) Develop data and information that will be used to

- (i) evaluate studies, including feasibility studies;
- (ii) support farmer education programs for efficient use of on-farm water for optimum production of agricultural crops; and
- (iii) guide the development of irrigation projects.

(b) Assist in the training of staff to plan and carry out research and the demonstration of research results in water management.

C. Scope

1. The program will include planning and development of research programs and research station development at Pirapora, Sao Desiderio, and Formoso.
2. Some advisory support will be provided to guide on-going or new programs of research at Bebedouro, Pirapora, and Petrolandia.
3. Assistance will include programs of adaptive research and field trials of research results to provide a basis for farmer education and extension support.
4. Support will be given to development and professional improvement of the research staff, through seminars and selected consultant help.

D. Operation

1. Utah State University

(a) USU will provide the services of technical research staff as follows:

- (i) irrigation research specialist for an initial period of two years to arrive in Brazil by approximately March 1971;
- (ii) short term support in specialized areas as needed and requested by the USU specialist with USAID and SUVALE approval; and
- (iii) research agronomist as may be justified and mutually agreed by SUVALE, USU, and USAID on the basis of organizational development and operational needs.

(b) The USU staff will operate with the guidance and support of the director of Rural Development and, consistent with approved SUVALE programs, be expected to advise, assist, and maintain contact with the heads of research, head of irrigation and drainage division, chiefs of regional agencies, administrators of research stations, station agronomists and engineers, and with the superintendent of SUVALE as needs dictate.

(c) The USU staff will be headquartered in Rio de Janeiro, but will be expected to spend a major portion of time in the Sao Francisco Valley. In the event of movement of responsible SUVALE headquarters and

U.S. Assistance team personnel, USU staff will also be expected to move to a location providing easy and direct contact. Program needs should be the primary consideration.

(d) From time to time USU will send graduate students to Brazil to assist in the research program and pursue particular research for use in Master's theses or Ph.D. dissertations. This work will be consistent with or part of the cooperative programs with SUVALE.

(e) The Contract AID/csd-2167 provides salary, per diem, international travel, and shipment of effects for all USU personnel.

2. SUVALE

SUVALE will provide office quarters, equipment consistent with program needs, secretarial service, and in-country transportation as necessary to carry out the program.

SUVALE will also provide the field equipment, farm machinery, laboratory equipment, technical supplies, seeds, fertilizer, staff, and facilities needed to plan and implement the research program as agreed upon with USU.

3. USAID/Brazil

The USAID Mission in Brazil will undertake to provide housing and related furnishings and privileges and immunities consistent with those accorded AID personnel and not foreclosed by the contract.

E. Reporting

USU staff will appraise SUVALE and USAID/Brazil of major developments in the field work and prepare an annual report to SUVALE with three (3) copies to USAID/Brazil.

A yearly plan of work should be prepared within a reasonable time after arrival of USU staff to serve as a guide. This plan of work should have the approval of SUVALE and USAID/Brazil.

F. Development and Use of Technical Data and Reports

The USU staff will be permitted to pursue individual studies based on research programs of SUVALE designed to further the international objectives of Contract AID/csd-2167 with appropriate credit to SUVALE and Brazil and USAID/Brazil.

G. Relations with USAID/Brazil

The USU staff will be expected to consult with and otherwise keep USAID/Brazil informed with respect to their operations and to conduct their program in such a manner as to be consistent with Mission programs and objectives.

H. Amendments

Amendments or changes in this memorandum of understanding and agreement can be made as needed by an exchange of letters indicating the approval of USU, SUVALE, and USAID/Brazil.

APPENDIX C

WATER MANAGEMENT RESEARCH

Memorandum of Understanding and Agreement

Colombia

A. Introduction

This memorandum will outline in general terms the working relationships in which ICA and INCORA will utilize the cooperation of Utah State University (USU) in a program of Water Management Research in Colombia. USU will provide services in conformity with AID Contract csd-2167, with the approval of AID/Colombia and the Colombian National Department of Planning. (Planacion)

B. Purpose

The purpose of USU's cooperation is to assist ICA in planning and carrying out a program of water management research at selected research stations or locations in Colombia. The data and information obtained will be used in the national development of land and water resources in Colombia and elsewhere as applicable. Such information will be of special interest to agencies such as INCORA in the development of irrigation districts and to farmers in general. It is expected that this program will be an integral part of the program of ICA for reserach in Colombia.

C. Scope of Work

The work outlined in this section will be undertaken by the USU staff member assigned to the program working directly with the counterparts assigned by ICA. The USU staff member will provide the technical leadership to plan and implement the research program but in consultation with his counterparts. Additional technical backstopping will be provided by USU staff as needed.

1. Description

a. Field work on the light soils (in Atlantico-3). This will include:

(1) Continuation of the studies using the tile drains to obtain data on drain characteristics and spacing. Additional observation wells and piesometers will be installed to measure water table fluctuations during the irrigation and rainy season. These data will be used to compute hydraulic conductivity and transmissibility of the soil, and be correlated with irrigation applications, rainfall, and evapotranspiration.

(2) A determination of the nature and extent of the salinity and/or sodic problem through both physical and chemical laboratory analysis of soil samples.

(3) Continue the determination of intake rate of affected and non-affected areas. Soils in natural condition as well as treated soils will be used.

(4) Procedures found effective in 3 above will be used in field trials on plots adjacent to the newly constructed open drains where water table build-up will not interfere with the studies.

b. Field work on the heavy soils. There are two basic problems to be solved by research on the heavy soils.

(1) Determine the criteria by which subsurface drainage can be accomplished economically.

(2) Determine and define the management practices that will minimize water table build-up and optimize productivity and farmer income under given conditions.

c. The following procedures will be used:

(1) Determine the hydraulic conductivity, specific yield, and transmissibility of the subsoils in representative areas.

(2) Establish an experimental area in a selected site where a pilot drainage system can be installed.

(3) Determine the rate of water table build-up and the effectiveness of the pilot drainage system. Such an experiment should be operated for a period of three years or longer to obtain the desired information.

(4) To determine the irrigation interactions with crop varieties, plant populations, and fertilizers for optimum production of crops.

(5) Determination of actual and potential evapotranspiration. A suitable lysimeter will be installed and operated over a sufficient length of time to obtain reliable results. Field soil moisture sampling techniques will be used to study water use on field crops grown.

(6) Supplement data now being obtained at existing meteorological stations in the area. Important parameters such as wind velocity are not now being measured.

(7) Measure surface runoff from both rainfall and irrigation on the experimental areas. Precipitation and water applications will be measured at the site.

(8) Tests of a modified mole drain system will be made at selected sites in Colombia. Included in these will be Atlantico-3, Magdalena 1, Tibaitata and other areas as conditions permit. These tests will be monitored for effectiveness - resistance to failure, life, power requirements and other factors important to good farm drainage.

(9) Plan and implement a field research program to determine the irrigation interactions with crop varieties, plant populations and fertilizers for optimum production of crops in "Marconia" ICA Research Station, located on INCORA Project Magdalena 1.

D. Reporting and Use of Data

1. Reporting

USU's staff will inform ICA, INCORA, AID/Colombia, and USU of major developments in the field work and will prepare an annual report to above agencies. A yearly detailed plan of work will be prepared within 60 days after the arrival of USU staff to serve as a work guide.

2. Development and Use of Technical Data and Reports

The USU staff as well as ICA or INCORA staff will be permitted to use data from the studies undertaken in the program for theses or dissertations in pursuing a program for the Masters or Ph.D. degree. Also the data can be used to provide information to other countries of the world where applicable. Appropriate credit should be given to the sponsoring agencies; AID/Washington, Contract csd-2167, ICA, INCORA, and AID/Colombia.

E. Contributions - Utah State University

1. Personnel

Number	Field of Specialization	Duration of assignment in months
1	Drainage & Irrigation Engineer	24
1	Agricultural Engineer - Irrigation interactions, crops, soils.	24
1	Drainage consultant	2
1	Experimental Design Analyst	3
1	Evapotranspiration and Water Requirements	3
4	Technical assistants for research programs	12

TDY Personnel:

Since the experimental programs involve several disciplines, it is anticipated that specialist help will be needed to answer specific problems as they arise in the field. Where possible, the technical expertise within ICA and AID through contract personnel now in Colombia will be requested to help solve the problem. Where this is not possible technical consultants on a TDY basis will be available from Utah State University. The estimate of need of USU TDY staff is indicated in the above chart. Timing of visits will be at the discretion of the USU staff member and the ICA counterparts.

The technical assistants for research programs will mainly involve students working on the AID 211D institutional grant program. Students in this program will be doing research for their masters thesis or their Ph.D. dissertation.

2. Equipment and Transportation

a. The contract will allocate funds to purchase limited, essential technical equipment to carry out the program. (See budget.) This will be as agreed upon by the personnel assigned by the University and ICA.

b. Utah State University will purchase 2 vehicles for transportation. The vehicles will be maintained by USU. Title to the vehicles will be in the name of ICA and they will be turned over to ICA when the cooperative project is completed.

F. ICA Personnel

1. Two counterparts of professional competence and technical personnel to work with USU personnel in (a) Atlantico-3 (b) Marconia at Magdalena 1.

Field workers as required to implement the experimental program.

2. Lands and Water

Appropriate land areas with adequate water supply to assure irrigation when needed.

3. Transportation

Provide transportation for its own personnel in keeping with the needs of the program.

4. Office Space and Secretarial Help and Office Supplies

Provide office space for USU personnel and counterparts with sufficient secretarial assistance and supplies to assure adequate reporting data recording and carrying out the normal activities of such a program.

5. Equipment and Supplies

Provide the farm machinery and other equipment necessary to land preparation, cultivating, harvesting, irrigation, and other such necessary work.

G. Contributions - INCORA

The two areas of work presently selected for research work are on projects of INCORA. Also INCORA and ICA are presently working on plans for ICA to take over the operation of a particular research demonstration area. It therefore seems appropriate to cooperate with INCORA and have INCORA provide general support as follows:

1. Personnel

Technical collaboration with appropriate INCORA-ICA and USU staff to develop understanding of the status of the project and the problems needing research.

2. Provide field workers for particular assignments as needed for the experimental work progress. This is estimated at 48 man/months.

3. Other

Use of equipment to prepare land as needed where such equipment is not yet available through ICA.

H. Contributions - USAID/Colombia

The USAID/Colombia will provide the privileges and immunities consistent with those accorded USAID personnel and not foreclosed by the contract.

I. Relations with USAID/Colombia

The USU staff will be expected to consult with and otherwise keep USAID/Colombia informed with respect to their operations and to conduct their program in such a manner as to be consistent with Mission programs and objectives.

J. Changes and Amendments

Amendments or changes in this memorandum of understanding and agreement can be made as needed by an exchange of letters indicating the approval of ICA, INCORA, USU, USAID/Colombia, and Planacion.

BUDGET

Estimate of Monies Programmed
for Expenditure for Colombia under
Contract AID/csd-2167

	First year	Second year Estimated
Personnel (USU staff & consultants)	37,414	35,000
Housing	5,200	5,200
Travel		
International (staff member & family)	6,000	6,000
In country	4,000	4,000
Per Diem	1,200	1,200
Transportation Household effects	4,000	4,000
Equipment and Supplies	5,000	3,000
Education Allowance	1,200	1,200
Vehicles	9,600	--
TOTAL	73,614	59,600

APPENDIX D

DRAINAGE AND SALINITY PROBLEMS IN IRRIGATION PROJECTS OF COLOMBIA

Plan of Work and Progress Report

Personnel

Dr. Edwin C. Olsen, USU - Full Time
Prof. Jerald E. Christiansen, USU - Short Term

Objectives

The activities initiated in July-September of 1969* will be continued and expanded in the Atlantico-3 project of Colombia. Specific work will be oriented to the solution of two main problems:

1. Determination of the drainage requirements and design criteria for water table control on the non-saline soils.
2. Reclamation and improvement of salt affected areas.

Field work on the light soils. This will include:

1. Continuation of studies using tile drains to obtain data on drain characteristics and spacing. Installation of additional observation wells and piezometers to measure water table fluctuations during the irrigation and rainy season. Data collected will be used to compute the hydraulic conductivity and transmissibility of the soil and will be correlated with irrigation applications, rainfall and evapotranspiration.

2. Determination of the nature and extent of the salinity and/or sodic problem through both physical and chemical laboratory analysis of soil samples.

3. Continuation of studies to determine the intake rate of affected and non-affected areas. Soils in natural condition as well as treated soils will be used. Procedures found effective will be used in field trials on plots adjacent to the newly constructed open drains where water table build-up will not interfere with the studies.

Field work on the heavy soils. There are two basic determinations to be made through research on the heavy soils. These are:

1. The criteria by which subsurface drainage can be accomplished economically.

2. The management practices that will minimize water table build-up and optimize productivity and farmer income under given conditions. The procedures outlined below will be followed:

a. Determine the hydraulic conductivity, specific yield and transmissibility of the subsoils in representative areas.

b. Establish an experimental area in a selected site where a pilot drainage system can be installed.

c. Determine the rate of water table build-up and the effectiveness of the pilot drainage system. Such an experiment should be operated for a period of three years or longer to obtain the desired information.

d. To determine the irrigation interaction with crop varieties, plant populations, and fertilizers for optimum crop production.

e. Determine the actual and potential evapotranspiration. A suitable lysimeter will be installed and operated over a sufficient length of time to obtain reliable results. Field soil moisture sampling techniques will be used to study water use on field crops grown.

f. Supplement data now being obtained at existing meteorological stations in the area. Important parameters such as wind velocity are not now being measured.

g. Measure surface runoff from both rainfall and irrigation on the experimental area. Precipitation and water applications will be measured at the site.

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*Watts, Darrell G. Progress Report, "Reclamation studies on the light and medium textured soils of Project Atlantico-3 Colombia," Agricultural and Irrigation Engineering Department, Utah State University, January 1971.

Progress

The project agreement with the Government of Colombia covering the Water Management Research activity in Colombia has been signed by all parties concerned, and the nomination of Dr. Edwin C. Olsen as chief-of-party in Colombia has been similarly approved. An additional full time professional position has also been approved as a part of the Project Agreement, however, nominations for this position are still under consideration.

Dr. Olsen was recently in Colombia for three weeks (Nov. 17 - Dec. 9, 1970) on another program, but while there he and Professor Christiansen took the opportunity to meet in Barranquilla on November 28 with the Colombian officials from both the Instituto Colombiano Agropecuario (ICA) and the Colombian Agrarian Reform Institute (INCORA) who are directly concerned with the Water Management Research Program in the Atlantico-3 project. The purpose of the meeting was to reiterate the immediate objectives of the program and to outline an initial plan of work which could be inaugurated prior to the permanent arrival of Dr. Olsen on about February 1, 1971.

It was determined that the immediate problem was in the citrus grove planted in the light soils of the Santa Lucia Experiment Station. There are several saline spots scattered throughout the orchard, and with the high river levels as a result of the record rains in the mountains, the water table in the orchard is within 80 cm. of the soil surface. As a result several trees are dying. Dr. Olsen spent December 1 through December 4 in Barranquilla and the Atlantico-3 project with his two counterparts assigned to him by ICA. Together with INCORA soils personnel stationed at the El Limon Station in the project area, they reviewed the problem and visited the site in question. In order to obtain some detailed Benchmark data in the study area representative locations were selected from which to obtain soil samples for complete physical and chemical analyses. In addition locations were selected for the installation of lines of piezometers in order to determine precisely the variation of the phreatic level as well as the direction of water movement. These studies will occupy the time of the counterparts assigned to the project until February 1 and will yield a valuable basis from which a method of reclamation may be proposed.

Vehicles and several items of requisite field and laboratory equipment are presently either on order or out for bid.

APPENDIX E

"MEMORANDUM OF UNDERSTANDING AND AGREEMENT"

Between

THE AGENCY FOR INTERNATIONAL DEVELOPMENT

UTAH STATE UNIVERISTY

and

THE ECUADORIAN INSTITUTE OF HYDRAULIC RESOURCES

A. Introduction

This memorandum outlines in general terms the working relationship of Utah State University with the Ecuadorian Institute of Hydraulic Resources (INERHI) and the U.S. Agency for International Development to Ecuador (USAID/E). In conformity with the Contract AID/csd 2167 the Utah State University, with the approval of USAID/E, will cooperate with and advise INERHI on the following: reservation of water for whatever purpose in the public interest; reorganize a zone, watershed or valley for a better or more rational utilization of the water; designate zones of protection in which any activity that affects the water resources can be limited, conditioned or prohibited; proclaim states of emergency due to scarcity, contamination or other causes, and counsel INERHI, sanitary authorities or police authorities so that they may issue the necessary ordinances to effect protection of water, its control and distribution for the public interest, giving preference to the supply of cities and household needs; diversion of water from one watershed to another which requires development; substitution of one source of supply of water of one or more users for another of similar quantity and quality to obtain better use of the resources; likewise, as regards the community uses and the organization and functioning of Water Boards. At the same time advise in the technico-administrative organization for the administration of justice in water matters.

B. Objective

The fundamental objective of the program is the promotion of an increase of efficiency in the utilization of waters, the public security requirements when certain happenings occur, the community uses of waters as well as the functioning of Water Boards; the conduct of litigation or controversies which originate in the country over the uses of water. Data and information on improvements made in these matters from other countries will be employed. Moreover, regulations for implementing Art. 5 of the Water Law Project will be made.

C. Work Plan

1. Regional Work

b. Continue the collection of information of all types as it pertains to water rights and administration from all Latin American countries and from sources outside Latin America as they may be useful for the solution of Latin American water rights and administration problems. This would be accomplished by correspondence and direct contacts in other countries.

b. Furnishing information thus collected to those governments and individuals who could utilize the same in the solution of problems.

c. Develop a water law digest program for Latin America.

2. Ecuadorian Work

a. Study

1. Procure, examine, and study all laws, codes, decisions, and administrative regulations in force and proposed pertaining to water rights and administration in Ecuador, in accordance with existing laws.

2. Examine the history of operation and present status of governmental agencies as they relate to water administration.

3. Obtain and review available information on customary water use in Ecuador, and carry out studies on that matter.

b. Information

Make available to interested personnel in governmental agencies the information and consultations governing domestic and international water laws and administration on request and more specifically provide assistance and information especially on the matters listed in the introduction.

c. Technical Assistance

Assist in the determination of appropriate irrigation facilities for farmers to be benefited under the FY-1970 AID loans for Agricultural Enterprise Promotion and Agricultural Development and Diversification.

Major duties would be identification of potential water rights and water administration problems and assistance to INERHI and other relevant institutions in resolving these problems. Other duties would include assistance in identifying other potential technical problems related to on-farm water use.

3. Time Sequence

It is understood that the work outlined for Ecuador and area studies requested by USAID/E will take precedence over inter-regional work in accordance with the information needs of Ecuador.

D. Operation Inputs

1. Utah State University

a. USU will provide a water law and administration specialist for a two year period in accordance with the work plan.

b. The USU specialist will operate with the support of INERHI and maintain contact with the personnel who will supply the information for the studies and their incorporation into the information systems.

c. USU specialist will be headquartered in Quito.

d. Short time specialists and graduate students may be sent to Ecuador from time to time to assist the USU specialists.

e. Will provide in Ecuador an extensive microfilm library in the field of water law and administration, the law of international lakes and rivers, and water resources development, all for the use of the specialist and Ecuadorian collaborators.

f. The contract will provide international travel for staff member and family, shipment of personal effects, salary and per diem costs, and other support as required under the contract.

2. Ecuador

a. Copies of laws, regulations, publications and other pertinent information.

b. Advice and consultation time by INERHI personnel as is reasonably necessary for the execution of the work plan.

c. Office

d. Equipment

e. Bilingual Secretarial Assistance

3. USAID/Ecuador

a. The USU specialist will have privileges and immunities as normally accorded AID personnel in accordance with local regulations and as approved by the U.S. Embassy.

The USAID Mission will not be able to provide household furniture and local travel in Ecuador.

b. The USU staff shall consult with and keep USAID/E informed with respect to their operations and shall conduct their program in a manner consistent with mission programs and objectives.

E. Amendments

Amendments or changes in this memorandum of understanding and agreement can be made as needed by an exchange of letters indicating the approval of USU, INERHI, and USAID/Ecuador.

APPENDIX F

EL SALVADOR - MEMORANDUM OF UNDERSTANDING

This memorandum covers general responsibilities and contributions of the Utah State University, Logan, Utah; the Ministry of Agriculture and Livestock, El Salvador and the USAID Mission, El Salvador, in a joint program of Water Management Research. The Utah State activity in El Salvador is under AID Contract csd-2167.

The purpose of this program is to provide assistance to the Ministry of Agriculture and Livestock's Division of Irrigation and Drainage. The long term objectives are: (1) Develop a background of information in plant-soil-water relationships in El Salvador, (2) Train counterpart personnel in research methodology, experimental design, and evaluation of research data, and (3) Provide new research facts in a usable form for those agents working directly with farm operators.

The University will provide one full time research specialist in soil-water-plant relationships for a period of two years. The University, further, will furnish short term consultants who are experts in experimental design, saline and alkali soils, evapotranspiration, water requirements and other specialized fields as their needs are identified. These consultants will spend not to exceed a total of 15 man/months per year in El Salvador.

The University, through Contract csd-2167, will provide logistic and technical support to the team leader and the consultants. The team leader will have limited access to classified information not to exceed Confidential. All reports, statistical, and research compilations concerning this contract have been and will be made available by the Mission, the Ministry of Agriculture and Livestock and other related agencies of the Government of El Salvador.

Technical services agreed upon and provided for will be performed for the Government of El Salvador. General policy direction and guidance will be given by the Mission Director through the Food and Agriculture Officer. The latter will be the AID liaison official and will assist the contract team in planning and will coordinate the activities of this team with those of other teams working in agricultural programs. The University personnel will provide reports as follows:

1. Semi-annual and annual reports of progress.
2. Special reports as requested by the Food and Agriculture Officer.
3. Compilation of assignment reports by long and short term consultants upon completion of tour of duty and on the completion of the project.

Logistic Support in Kind Supplied by the Ministry of Agriculture and Livestock: Office space, office equipment, transportation in cooperating country, interpreter and secretarial services, 2 counterparts, laboratory and field workers, plot land and laboratory space, necessary machinery and equipment, seeds, fertilizers, etc.

By Utah State Contract: Necessary machinery and equipment*, specialists, technical support.

By AID: Housing and utilities**, furniture, household equipment, mission personnel privileges, technical support.

It is assumed that these services under the AID csd-2167 contract will extend for a period of five years or until one of the parties request termination of the program. This agreement is signed as a basis for mutual understanding.

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*Limited amounts of special equipment as provided in csd-2167 contract.

**Resident Advisor will receive standard AID allowances as provided in csd-2167 contract and in accord with mission policy.

APPENDIX G

IRRIGATION REQUIREMENTS IN LATIN AMERICAN COUNTRIES

by Jerald E. Christiansen and George H. Hargreaves,
Professor Emeritus and Research Engineer, respectively

INTRODUCTION

With increasing needs for the development of their natural resources, many Latin American countries are placing increased emphasis upon irrigation and the evaluation of the availability of moisture requirements for agricultural production. This is especially true of the northern South American and Central American countries such as Venezuela, Colombia, Ecuador, El Salvador, Honduras and Nicaragua where studies have been initiated. In some instances, project development has been undertaken where more careful studies may have indicated that the benefits to be derived from irrigation could not justify the expenditures involved. The need for irrigation in many places was not clearly established before the projects were constructed. This is unfortunate in that development capital might be more profitably used for other purposes such as fertilizers, flood control, transportation, etc. There appears to be a need for an overall study to more precisely determine the irrigation requirements. There is also a real need to define and use procedures that can be applied to all of the countries involved.

Development of Formulas and Equations

The development of formulas and other relationships used in this study has been accomplished primarily by the senior author over a period of years working with graduate students at Utah State University. To date some 14 Master of Science theses and some special reports have been completed on various phases of this problem. Concurrently the junior author worked on the problems under the auspices of the Bureau of Reclamation, Agency for International Development and the Inter American Geodetic Survey, and published several papers. These papers and theses are listed in the Bibliography. Space does not permit references to the bast bibliography now available on this subject.

Prepared for the Second World Congress of Engineers and Architects, Tel Aviv, Israel, December 14-18, 1970.

Note: The development of formulas, data gathering, and computer analysis required for this paper was financed by Utah State University, the Agency for International Development (Contract AID/csd-2167), the Inter American Geodetic Survey, and by OAS-CIDIAT (Centro Interamericano de Desarrolló Integral de Aguas y Tierras) under a contract with Utah State University.

Geographical and Climatological Characteristics

The countries in which studies have begun have many geographical and climatological characteristics in common, but they also have some very distinct differences. They all lie in the tropical zone, and have a twelve-month growing season when soil moisture is available. At any given location, mean monthly temperatures are fairly constant, generally varying less than 3 °C during the year. The temperature, however, varies greatly from place to place depending primarily on the elevation above sea level, and agriculture is carried on to elevations well above 3,000 meters in some of the Andean valleys of Ecuador, Colombia, and Venezuela. The mountains are generally lower in Central America but rise to fairly high elevations in Guatemala.

The precipitation patterns are generally similar, but the mean annual amounts vary widely from less than 400 mm per year in the more arid regions to more than 6,000 mm per year in the wetter areas. In some places, the mean annual precipitation varies more than two to one in distances of only a few kilometers. This is particularly noticeable in the states of Lara and Merida in Venezuela where there are very arid and very humid areas in close proximity. In general, the dry period begins in November or December and ends in April or May. There are, however, differing seasonal lags. The rainy season extends to February from Curarao to Trinidad, while it terminates in early October in the Yucatan. In some places precipitation is insufficient for optimum crop growth during every month of the year, and in other locations, precipitation is adequate during every month.

Although for any given location there is little variation in mean temperature from month to month, there is usually a relatively large variation in relative humidity, precipitation, sunshine percentage and wind velocity, and this is reflected in evaporation measurements. Evaporation is sometimes more than twice as much during the months of March and April as for the months of May to October. The daytime period from sunrise to sunset is fairly constant from month to month, generally varying less than one hour from January to July. Methods of estimating evapotranspiration based primarily on day length and mean monthly temperature, consequently, do not yield satisfactory results.

Terminology

The terminology used in the paper is that generally employed by American Engineers and Agriculturalists, but some terms have not been well standardized and may need defining. The following definitions and explanations are given to avoid misunderstanding.

Potential Irrigation Requirement, on a monthly basis, as used here is the estimated potential evapotranspiration less the dependable precipitation, as hereinafter defined. This potential irrigation requirement may be less than the actual irrigation requirement because it does not consider the irrigation efficiency, conveyance losses and drainage characteristics. For some months, where annual crops are grown, it may be more than the actual requirement because it assumes a full (100 percent) crop cover. Therefore, in project development, allowance must be made for storage and transmission losses in the system, for the irrigation application efficiency and kind of crop to be grown. These factors can be best estimated on a local basis so that proper allowances can be made in the project design.

Potential Evapotranspiration, ETP, is defined as the evapotranspiration loss from a short, vigorously growing, green crop that completely shades the ground (crop cover 100 percent) and where soil moisture is not a limiting factor. This corresponds to definitions given by Penman, Thornthwaite, Pruitt and others. This potential evapotranspiration may be less than that consumed by some taller crops, having a much greater total leaf surface, such as alfalfa, sugar cane, and bananas. It is greater than the consumptive use of annual crops during certain stages of growth. Total consumptive use requirements, on a project basis, must consider the crops to be grown and their monthly crop coefficients.

Actual Evapotranspiration or Consumptive Use depends not only on the potential evapotranspiration but on many other factors that reflect local conditions, including primarily, the percentage of crop cover, the availability of soil moisture, and depth and distribution of rooting of the crop. Much research has been done to determine relations between the soil moisture potential and evapotranspiration. Space does not permit a thorough discussion of this subject. The crop cover percentages, and the effect of maturity of the crop on evapotranspiration varies widely with different crops and is quite different for annual crops than for perennial crops.

The timing for planting, cultivation, and harvesting of annual crops in the tropics is very different than in the temperature zone and depends primarily on the precipitation pattern rather than upon the temperature. It has been found in Venezuela, for example, that little field work such as planting or cultivating, can be done in any month when the precipitation exceeds about 80 mm. Some fairly dry periods during the year are, therefore, essential for the production of such crops. Harvesting can also be accomplished more effectively during the drier periods. A fully adequate moisture supply every month of the year is not necessarily the most desirable for annual crops, but is generally most desirable for perennial crops, including pastures and orchards.

Pan Evaporation is that evaporation measured with a Class A evaporation pan under standard conditions. Many Class A pan installations do not meet these standards, and the effect is generally to increase the evaporation. For example, in comparing the evaporation from a standard pan in a large grassed area, with a nearby pan on bare soil, Pruitt (9) found that the evaporation from the pan on bare soil was more than twenty percent higher during the summer months than that from the pan on the grassed area. Discoloration inside the pan, or on the outside increases the absorption of radiant energy and increases the evaporation. Shading, reduced air movement over the pan resulting from nearby obstructions, screens over the pan, etc., may reduce the evaporation below that of a standard pan.

Class A pans provide a convenient drinking fountain for birds and sometimes for animals in many arid places, and measurements may be unreliable unless the pans are screened. The effect of screens is to reduce evaporation, but the relative amount is not well understood. For these reasons, pan evaporation measurements are not always reliable and are usually somewhat higher than for a standard pan properly cared for.

Dependable Precipitation, PD, is herein defined as the mean monthly precipitation that occurs on a probability basis three years out of four, or seventy-five percent of the time. This seventy-five percent probability basis is arbitrary but has been selected by the authors as being a practical and realistic value to use for general conditions.

In most agricultural areas precipitation varies widely from year to year, both in annual amounts and with respect to monthly values. These variations are particulary notable during transition months. For example, in the tropical areas of Central America, the Carribean, and northern South America, April is a transition month.

Rainfall in April of one year may be as much as one hundred times the rainfall during April for the preceding year. Under these conditions average precipitation is not a reliable measure of the amount of moisture that can be depended on for agricultural production.

In defining dependable precipitation it is necessary to consider the crops to be grown. Bananas and tobacco are much more sensitive to drought than are general crops. In the planning for the production of bananas on a commercial scale it seems desirable to select conditions where the probability of having adequate moisture in any one month is in the order of 85 to 90 percent of the time. Since there will be some moisture carryover from previous months, some deficiency one year in ten or one in seven is not considered critical to economic production.

This study considers general agricultural production. For a diversified agriculture including most tree and field crops it is believed that some deficiency can be tolerated in a given month during one year out of four. The seriousness of economic loss is decreased because of the probability that one deficient month will not follow or be followed by a deficient month and also because many soils are capable of carrying forward 100 to 200 mm of available moisture in the crop root zone.

For the precipitation data from Latin American that have been analyzed, the dependable precipitation has been found to vary from zero for the driest months, to from twenty to forty percent of the mean monthly precipitation in the more arid locations and for the transitional months, to more than eighty percent of the mean monthly precipitation for the wettest months.

Effective Precipitation, PE, is the amount of the precipitation that enters the soil and is held within the root zone for utilization by the crops grown. This effective precipitation is dependent upon many factors, including rainfall intensities, vegetative cover and soil infiltration rates, land slopes, root zone depths, soil drainage conditions, the soil moisture and storage capacity and the evapotranspiration rates. It does not appear feasible to include estimates of the effective precipitation in country-wide or regional studies. It seems preferable to leave consideration of this subject to those engaged in local project studies. In areas where precipitation intensities are high and infiltration rates relatively low, runoff may account for an appreciable percentage of the precipitation, and the effective precipitation may be appreciably less than the dependable precipitation as used herein.

Climatic Parameters. The climatic parameters that have greatest influence on the evapotranspiration are: temperature, humidity, incoming solar radiation, and wind velocity. In most countries, radiation is measured at relatively few locations. Sunshine hours, or sunshine percentage, is generally measured and reported for many more stations. Precipitation is measured in many locations where no other measurements are made. In Venezuela there are many locations where precipitation and pan evaporation are measured, and some places where temperature, or temperature and relative humidity, are also measured. Where Class A pan evaporation is measured, wind velocities at a height of sixty cm above ground level are usually measured and reported but not always. Wind velocities are also sometimes measured at two, six or ten meters above ground level. Sometimes wind velocities are measured and reported but no mention is made of the height of annemometer, or method of measuring the wind velocity.

Since the available data range from a large amount of precipitation data to relatively few data from stations that measure and report complete data, much time and effort has been spent in developing relationships from which missing data can be reliably estimated from that reported. Wind velocities vary with height above ground. A study of available data by Gutierrez (18) indicated that none of the published formulas can be used to obtain reliable estimates of the wind velocity at a standard height when measured at another height. Several formulas for adjusting wind velocities that give satisfactory results have been developed for this purpose.

Many of the climatic parameters are interrelated. For example, a correlation has been found between sunshine percentage and the mean relative humidity and also temperature differences. In the countries involved in these studies, there are fairly satisfactory relationships between mean temperature and elevation, when considered on a monthly basis. All of these relationships have been used to fill in and expand the available data so that they can be analyzed with a digital computer. The development of the many relationships involved in these studies has consumed much time and effort.

OBJECTIVES AND PROCEDURES

Potential Irrigation Requirement

As has been indicated, the principal objective of the studies has been to reliably estimate the potential irrigation requirement as previously defined. Since this depends on the dependable precipitation as well as on the potential evapotranspiration, it was necessary to also make the best possible estimates of these parameters, and to then combine the results in tabular form, and where feasible to plot the results on maps.

Dependable Precipitation, PD

Precipitation for a large number of stations (more than 100 in Venezuela, 110 in Ecuador, 62 in Colombia, and 13 in El Salvador) have been tabulated, keypunched, and frequency analyses have been made. Periods of record for these stations have ranged from a minimum of 4 years to 75 years for one station in Venezuela. The 75 percent probability values, together with the minimum, mean and maximum monthly values were then keypunched, and several relationships have been developed from which the dependable monthly values could be estimated from either the mean precipitation, where only mean values are available, or from the mean and minimum monthly values where such data are available. For the Venezuela data, the best fit was obtained when separate equations were used for each month, but a very satisfactory general relationship was developed using coefficients (A and B) based on the mean annual precipitation. In the following equations the notation is, PM, mean monthly precipitation, PI, minimum monthly precipitation for period of record, and PMA, mean annual precipitation.

The monthly equations were of the form,

$$PD_M = A_M + B_M PM + C_M PM^2 \quad . . . . (1)$$

$$PD_M = A_M + B_M(PM + PI) \quad . . . . (2)$$

in which the subscript M refers to the month and where the monthly values of A_M ranged from -5 to -20 (mm/mo), B_M from .412 to .797, and C_M from .0004 to .0005.

The best general relationship was of the form,

$$PD = A + B(PM) \quad . . . . (3)$$

where

$$A = -.02\ PMA \quad . . . . (4)$$

and

$$B = .27\sqrt{PMA/100} \quad . . . . (5)$$

with a maximum value of 0.91

Estimating Pan Evaporation, EVP, and Potential Evapotranspiration, ETP

Since Class A pan evaporation data are numerous in comparison with potential evapotranspiration data, and also because most investigators reporting evapotranspiration data have compared their results with pan evaporation, the first attempts at developing a general equation were for pan evaporation. This work was done in connection with a study of Water Requirements of Marshlands* and the studies of Patil (15, 25). A later study by Patel (Patel and Christiansen (24)) showed that this type of formula developed from data from semiarid locations gave better results than several with which it was compared when applied to data from more humid locations.

The general equations for pan evaporation, EVP, and potential evapotranspiration ETP, are

$$EVP = K_{EV} R_T C_T C_{HV} C_{WV} C_S C_E \quad . . . . . (6)$$

$$ETP = K_{ET} R_T C_T C_{HT} C_{WT} C_S C_E \quad . . . . (7)$$

in which

K_{EV} is an appropriate dimensionless constant for pan evaporation

K_{ET} is a similar constant for potential evaporation

R_T is the extraterrestrial radiation, computed for month and latitude, and expressed as equivalent evaporation by dividing the radiation (cal/cm^2/day) by the heat of vaporation at the mean temperature, T_M, and converting to appropriate units, usually inches or mm per day or per month (Table 1)

C_T is a dimensionless coefficient dependent on the mean temperature (the same value can be used for estimating pan evaporation and for evapotranspiration)

C_{HV} is a similar coefficient dependent on the mean humidity (the humidity coefficient for evapotranspiration, C_{HT}, is somewhat different, since potential evapotranspiration varies less with humidity than does pan evaporation)

C_{WV} is a dimensionless coefficient for wind velocity, likewise slightly different from the coefficient for wind, C_{WT}, used for estimating evapotranspiration

C_S is a coefficient for sunshine percentage

C_E is a coefficient for elevation.

*J.E. Christiansen and J.B. Low, "Water Requirements of Waterfowl Marshlands in Northern Utah," Publication No. 69-12, Utah Division of Fish and Game, Salt Lake City, 1969.

The coefficients are dimensionless and most of them are of the general form,

$$C_P = A + BX + CX^N$$

where

C_P represents the coefficient for the specific parameter, P

X represents the ratio, P/P_O, where P is the parameter and P_O is the standard value of the parameter, approximately a mean value

N is an exponent of X, usually having a value of 2.

Note that A + B + C = 1.00.

Tentative values of these constants and coefficients for pan evaporation and evapotranspiration are:

$$K_{EV} = .35 \quad \ldots\ldots (6a)$$

$$K_{ET} = .28 \quad \ldots\ldots (7a)$$

$$C_T = .40 + .50\ (TM/25) + .10\ (TM/25)^2 \quad \ldots\ldots (6b)(7b)$$

(TM is mean temperature in °C)

$$C_{HT} = ((1.00 - HM)/.30)^{.25} \quad \ldots (7c)$$

(HM is mean relative humidity expressed decimally)

$$C_{HV} = -.60 + 1.60\ C_{HT} \quad \ldots (6c)$$

$$C_{WV} = .60 + .46\ (W10/8) - .06\ (W10/8)^2 \quad \ldots\ldots (6d)$$

(W10 is wind at an instrument height of 10m in Km/Hr.)

$$C_{WT} = .70 + .36\ (W10/8) - .06\ (W10/8)^2 \quad \ldots\ldots (7d)$$

$$C_S = .48 + .66\ (S/.5) - .14\ (S/.5)^2 \quad \ldots\ldots (6e)(7e)$$

$$C_E = 1.00 + .06\ (EL/1000) \quad \ldots (6f)(7b)$$

(EL is elevation in meters)

ETP is defined as that equivalent to evapotranspiration for rye grass measured with a 20-foot (6.1 m) diameter weighing lysimeter (Pruitt (8,9,10)).

Pan evaporation and potential evapotranspiration can likewise be estimated from measured solar radiation, R_S, and climatic data.

The general equations are

$$EVP = K_{SV} R_S C_T C_{WV} C_{HV} \quad \ldots\ldots (8)$$

$$ETP = K_{ST} R_S C_T C_{WT} C_{HT} \quad \ldots\ldots (9)$$

in which K_{SV} and K_{ST} are appropriate constants and R is the measured incoming radiation expressed in terms of equivalent evaporation. When using measured radiation, coefficients for sunshine and elevation can be omitted.

Our studies have shown that reliable estimates of incoming radiation can be made from an equation originally developed by Pizarro (26).

$$R_S = K_R R_T C_S C_E \quad \ldots\ldots (10)$$

in which the coefficients C_S and C_E are the same as given in 6e, 6f. Values of K_{SV}, K_{ST} and K_R that give fairly good results for both Davis, California, and Venezuela and Ecuador are:

$$K_{SV} = .69 \quad \ldots\ldots (11)$$

$$K_{ST} = .55 \quad \ldots\ldots (12)$$

$$K_R = .51 \quad \ldots\ldots (13)$$

It can be seen that for consistent relationships,

$$K_{EV} = K_R K_{SV}, \text{ and} \quad \ldots\ldots (14)$$

$$K_{ET} = K_R K_{ST} \quad \ldots\ldots (15)$$

ETP Using Vapor Pressure Deficit

Since according to Dalton's law, evaporation is a function of the vapor pressure deficit, an attempt was made to develop a satisfactory formula using the vapor pressure deficit, or a coefficient for vapor pressure deficit, in lieu of the separate coefficients for temperature and humidity. The best fit was obtained with the latter, and the equation for the coefficients for vapor pressure deficit in millibars, VPDMB, were

$$C_{VPDV} = .25 + 1.00(VPDMB/10) - .25(VPDMB/10) \quad \ldots (16)$$

$$C_{VPDT} = .32 + 0.86(VPDMB/10) - .18(VPDMB/10) \quad \ldots (17)$$

These coefficients, however, did not give as good a fit as did the separate coefficients, CT and CH. The vapor pressure is seldom reported in meteorological records and, therefore, must be computed from the temperature and humidity using certain assumptions that at best are only approximations. The principal difficulty is that the evaporation from the pan is actually a function of the difference in vapor pressure of the water in the pan and the vapor pressure in the atmosphere above the water surface. The water temperature is not the same as the air temperature. The water temperature lags behind the air temperature, and the mean daily value of the difference depends on the cooling effect of the evaporation, which in turn depends on parameters causing the evaporation, such as humidity and wind. From a practical point of view there appears to be no advantage in using vapor pressure deficit, or a more theoretical approach, because it greatly complicates the problem if one is to obtain an equally good fit.

Where Sunshine Percentage and Radiation Are Not Available

A problem that has presented itself in connection with the Latin American study is how to obtain equally satisfactory results when neither sunshine percentage nor radiation data are available. In Ecuador, for example, only 18 of 114 climatological stations report the sunshine percentage, and for those that do, the mean value was about 30 percent, much lower than for any other country that has been studied. Only five stations report measured radiation. In Venezuela, 9 of 13 stations operated by the Ministry of Public Works, MOP, or Ministry of Agriculture, MAC, report sunshine, and only 8 report radiation. Because of the interrelationships between sunshine percentage, humidity and the difference between the mean monthly values of maximum and minimum temperature, three possible approaches were investigated:

1. Determine the mean monthly value of sunshine percentage for the stations for which it is available, and use these values for all stations for which it is not available.
2. Determine the best relationship between sunshine percentage and other parameters, temperature, temperature difference, humidity, elevation, etc., and use such relationships to estimate sunshine percentage.
3. Develop equations and coefficients for computing evaporation and evapotranspiration that do not include coefficients for sunshine percentage. This approach has given the best fit for the Davis, California; Venezuela; and Ecuador data. The equations that have been developed are:

$$ETP = K_{ET2} R_T C_{T2} C_{H2} C_{W2} C_{TD} \quad \ldots (18)$$

$$EVP = 1.35\ ETP \quad \ldots\ldots (19)$$

in which

$$K_{ET2} = .264 \quad \ldots\ldots (18a)$$

$$C_{T2} = \sqrt{TM/25} \quad \ldots\ldots (18b)$$

$$C_{H2} = .50 + .50\ (1.00 - HM)/.30 \quad (18c)$$

$$C_{W2} = .70 + .30\ W10/8 \quad \ldots (18d)$$

$$C_{TD} = .90 + .10\ TD/10 \quad \ldots (18e)$$

(TD is mean maximum minus mean minimum temperature in °C)

R_T = as previously defined

Potential Irrigation Requirements

Computer programs were developed for computing the monthly evapotranspiration deficit, or difference between the computed potential evapotranspiration and the dependable precipitation. Since for most locations, only precipitation data, or precipitation and pan evaporation data are available, potential evapotranspiration must be estimated from the relationships developed from the data for the limited number of stations for which climatic and/or evaporation data are available. For example, in Venezuela, the mean monthly ratios of the computed potential evapotranspiration to the measured pan evaporation were used to estimate potential evaporation for the

53 stations for which pan evaporation was available. For the other stations for which only precipitation was available, monthly estimates of pan evaporation or evapotranspiration were made from relationships that depended on location, elevation of the station, and monthly precipitation. Since the computed evapotranspiration does not vary nearly as much from place to place as does precipitation, the probable accuracy in the final result is more dependent on the reliability of the precipitation data than on estimated evapotranspiration.

Examples of computer print-out for two stations in Venezuela are given in Tables 2 and 3.

Table 2 represents a humid location where the mean annual precipitation is 2616 mm, and where there is only a very small deficit during four months of the year. Irrigation would not be economically justified under such conditions. The precipitation pattern for this station is also not typical of most locations in Venezuela.

Table 3 is for an arid location where the mean annual precipitation is only 628 mm per year, and where the ET deficit, or potential irrigation requirement has a positive value every month of the year, ranging from a 78 mm in November to 266 in July. This monthly distribution is not typical of most places in Venezuela where the maximum ET deficit is for March.

Print-outs of this kind have been made for the 53 stations for which only precipitation and pan evaporation data are available. The evapotranspiration deficit (potential evapotranspiration minus dependable precipitation) provides an index of potential irrigation requirements.

CONCLUSION

Class A pan evaporation data have been widely used as a measure of irrigation requirements. Since, however, reliable and well-standardized evaporation data are not generally available, the authors recommend the use of equations for estimating potential evapotranspiration. These equations are evaluated in each area of use by comparing their results with measured pan evaporation data. Potential evapotranspiration can be calculated with a good degree of accuracy provided data are available for temperature, sunshine percentage, wind and humidity. When sunshine data are not available, modified equations provide usable results.

The equations presented provide a measure of the effect of climatic zone differences upon plant or crop evapotranspiration. The principal other factors that determine the amounts of evapotranspiration are those relating to cultural practices and rates and stages of growth. Actual evapotranspiration can be made to vary over a considerable range by modifying cultural and irrigation practices.

Computations of potential evapotranspiration and of potential irrigation requirements provide a valuable starting point in the evaluation of climate as a development resource, the determination of the needs and requirements for irrigation and in the estimation of actual irrigation requirements. Methods described may be combined with crop coefficients given by Christiansen and Hargreaves (3) and used for the computer scheduling of irrigation applications or irrigation system operations. Dependable precipitation as herein defined is an important determining factor in the evaluation of climate or in the estimation of irrigation requirements.

The study reported here is still in progress and much remains to be done. The problem being studied at the moment is how to obtain the best estimate of potential irrigation requirement where only precipitation data are available.

Table 1. Mean Monthly Values of Extraterrestrial Radiation

Latitude degrees	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Expressed as equivalent evaporation in millimeters per day											
North												
60	1.41	3.36	6.88	11.31	15.14	17.06	16.25	13.03	8.67	4 58	1.92	0.96
55	2.55	4.62	8 08	12.18	15.55	17.18	16 50	13.71	9.77	5.85	3.11	2.02
50	3.77	5.89	9.23	12.98	15.93	17.30	16.73	14.34	10.79	7.09	4.35	3.21
45	5.04	7.14	10.30	13.69	16.23	17.38	16.91	14.87	11.74	8 30	5.63	4.46
40	6.32	8.36	11.30	14.31	16.45	17.38	17.01	15.32	12.59	9.45	6 90	5.75
35	7.59	9 53	12 21	14.82	16.58	17.30	17.01	15.66	13.35	10.54	8.15	7.04
30	8.84	10.64	13.03	15.23	16.60	17.13	16 92	15.90	14.01	11.55	9.36	8.32
25	10.05	11 68	13.75	15.52	16.51	16.85	16.72	16.02	14.56	12 48	10.53	9.56
20	11.20	12.64	14.37	15.70	16.32	16.48	16.42	16.04	15.00	13.33	11.63	10.76
15	12.29	13.51	14.88	15.77	16 02	16.00	16 02	15.93	15 33	14.07	12.66	11.91
10	13.30	14.28	15.27	15.72	15.61	15.42	15.51	15.72	15.54	14.71	13.61	12.98
5	14.23	14 96	15.55	15.55	15.09	14.74	14.90	15.39	15 63	15.24	14.47	13.98
0	15.07	15.53	15.71	15 27	14.47	13.97	14.19	14.95	15.61	15.66	15.23	14.90
South												
—5	15.81	15.98	15.75	14.88	13.76	13.12	13.39	14.41	15.46	15.96	15.89	15.72
—10	16.45	16.33	15.67	14.37	12 95	12.18	12.51	13.76	15.20	16.15	16.45	16.44
—15	16 98	16.55	15.48	13.76	12.06	11.17	11.54	13.01	14.82	16.21	16.89	17.06
—20	17.40	16.66	15.16	13.05	11 09	10.10	10.51	12.17	14.33	16.16	17.22	17.57
—25	17.71	16.65	14.73	12.24	10 05	8.97	9.42	11.25	13.73	15.99	17.43	17.97
—30	17.91	16.52	14.19	11.34	8 95	7.80	8.28	10.25	13.03	15.70	17 54	18.27
—35	17.99	16.27	13.54	10.36	7.30	6.61	7.10	9.18	12.23	15.29	17.52	18.46
—40	17.98	15.92	12.79	9.31	6.61	5.40	5.89	8.06	11.33	14.78	17.40	18.54
—45	17.86	15.46	11.94	8.19	5.41	4.19	4.69	6.89	10.35	14.16	17.18	18.54
—50	17.66	14.90	11 00	7.02	4.20	3.02	3.49	5.68	9.29	13.45	16.87	18.46
—55	17 40	14.25	9.98	5.81	3.01	1.90	2.34	4 46	8.16	12.64	16.49	18.33
—60	17.12	13 54	8.88	4.57	1.88	0.91	1.28	3.24	6.97	11.76	16.07	18.20

Table 2. Analysis of Pan Evaporation and Precipitation Data at La Fria, Venezuela - Elevation 120 m

Pan Evaporation for 1962 to 1967

Precipitation for 1950 to 1967

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANN
VALUES IN MILLIMETERS													
AVERAGE PAN EVAPORATION	136.	126.	140.	152.	148.	153.	172.	181.	182.	183.	121.	115.	1808.
AVERAGE EV-TRANS. POT.	93.	83.	89.	100.	107.	123.	140.	150.	143.	138.	92.	85.	1345.
AVERAGE PRECIPITATION	184.	163.	143.	278.	300.	144.	155.	163.	185.	320.	283.	300.	2616.
DEPENDABLE PRECIPITATION	129.	112.	95.	209.	228.	96.	105.	112.	131.	245.	214.	228.	2320.
AVERAGE ET DEFICIT	-37.	-28.	-6.	-109.	-120.	26.	35.	39.	12.	-107.	-121.	-143.	112.
AVERAGE MONTHLY PERCENTAGES													
PAN EVAPORATION	7.5	7.0	7.8	8.4	8.2	8.5	9.5	10.0	10.1	10.1	6.7	6.4	100.0
EVAPOTRANSPIRATION POT.	6.9	6.2	6.6	7.5	8.0	9.1	10.4	11.2	10.6	10.3	6.9	6.3	100.0
PRECIPITATION	7.0	6.2	5.5	10.6	11.4	5.5	5.9	6.2	7.1	12.2	10.8	11.5	100.0
DEPENDABLE PRECIPITATION	5.6	4.8	4.1	9.0	9.8	4.2	4.5	4.8	5.6	10.5	9.2	9.8	82.1
EVAPOTRANSPIRATION DEF.	.0	.0	.0	.0	.0	23.7	31.2	34.5	10.5	.0	.0	.0	100.0

Table 3. Analysis of Pan Evaporation and Precipitation Data at Corora La Granja, Venezuela - Elevation 420 m

Pan Evaporation for 1958 to 1967

Precipitation for 1950 to 1967

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANN
VALUES IN MILLIMETERS													
AVERAGE PAN EVAPORATION	256.	276.	306.	244.	231.	295.	328.	320.	264.	218.	182.	218.	3139.
AVERAGE EV-TRANS. POT.	175.	182.	194.	162.	168.	237.	256.	266.	207.	164.	140.	162.	2324.
AVERAGE PRECIPITATION	26.	11.	27.	56.	86.	27.	21.	39.	80.	119.	104.	33.	628.
DEPENDABLE PRECIPITATION	0.	0.	0.	21.	47.	0.	0.	7.	42.	75.	62.	2.	481.
AVERAGE ET DEFICIT	175.	182.	194.	140.	121.	237.	256.	259.	166.	89.	78.	160.	2068.
AVERAGE MONTHLY PERCENTAGES													
PAN EVAPORATION	8.1	8.8	9.8	7.8	7.4	9.4	10.4	10.2	8.4	6.9	5.8	7.0	100.0
EVAPOTRANSPIRATION POT.	7.5	7.9	8.4	7.0	7.2	10.2	11.5	11.5	8.9	7.1	6.0	7.0	100.0
PRECIPITATION	4.1	1.7	4.3	8.8	13.7	4.4	3.3	6.2	12.7	19.0	16.6	5.2	100.0
DEPENDABLE PRECIPITATION	.0	.0	.0	4.4	9.7	.0	.0	1.5	8.7	15.6	12.9	.4	53.1
EVAPOTRANSPIRATION DEF.	8.5	8.8	9.4	6.8	5.9	11.5	12.9	12.5	8.0	4.3	3.8	7.7	100.0

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