AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

Batch #24

1. SUBJECT CLASSIFICATION

A. PRIMARY: Serials — Y-AP10-0000-0000

B. SECONDARY: Agriculture--Water resources and management

2. TITLE AND SUBTITLE

Water management research in arid and sub-humid lands of less developed countries; annual progress report,1971/1972

3. AUTHOR(S)

(101) Utah State Univ. Dept.of Agr.and Irrigation Engineering

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1972	51p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Utah State

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

(Research summary)

9. ABSTRACT

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-RAB-447	

12. DESCRIPTORS

Irrigation
Latin America
Water resources

13. PROJECT NUMBER

14. CONTRACT NUMBER

CSD-2167 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

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

Contract AID/csd-2167

Fourth Annual Progress Report

November 1, 1971, to October 31, 1972

to

The United States Agency
for International Development

prepared by

The Department of Agricultural
and Irrigation Engineering

Utah State University
Logan, Utah 84322
USA

TABLE OF CONTENTS

Summary of Accomplishments and Utilization . . . iv

General Background 1

Project Objectives 2

General Objective 2

Specific Objectives 2

Continued Relevance of Objectives 3

Objective; Conservation of Rainfall and Limited Supplementation by Irrigation 5

A. Pirapora, Brazil 5

B. Aconcagua Valley, Chile 6

Objective; On-Farm Water Conveyance, Control, Measuring and Delivery Systems 6

A. Bolivia 6

B. Brazil 6

1. Pirapora 7

2. Formoso 7

3. Barreiras 8

4. Small Irrigation Projects 9

C. Chile 10

D. Ecuador 10

E. Venezuela 11

Studies Outside of Latin America 11

Objective; Surface and Sub-Surface Water Removal Systems 12

A. El Salvador 12

B. Colombia 13

C. Utah 14

Mole Plows 14

Objective; Land Preparation and Leveling Related to Water Management, Erosion, Water Infiltration and Good Land Use and Cropping Practices 17

A. Chile 17

B. Colombia 18

Objective; Water Application Methods 19

A. Chile 19

B. Colombia 21

1. Sesame 22

2. Soy Beans 23

3. Corn 23

4. Sorghum 24

C. El Salvador 27

D. Brazil 28

1. Pirapora 28

2. Formoso 29

3. Barreiras 29

Objective; Integration of Water-Use Factors into a Productive Cropping System 30

Hydrologic Model Simulation 30

Special Projects 32

Objective; Control of Salinity and Enchangeable Sodium 32

Chile 32

Colombia (see I-C-3)) 13

Objective; Institutional Factors Influencing Farm Water Utilization 33

A. Water Law Component 33

B. Economic Component 35

Appendices . . . . . .

A. Publications . . . . . .

B. "Water Legislation in the Andes Pact Countries Summary and Comparison Table of Contents" . . . .

SUMMARY OF ACCOMPLISHMENTS AND UTILIZATION

All of the specific on-farm water management research studies have been directed toward accomplishing one or more of the eight project objectives. Evidences of accomplishment and utilization in cooperating countries have greatly increased during the last year.

Agricultural research plots in Brazil, Chile, Colombia and El Salvador are yielding data on the interaction of water with fertilizers, crop varieties, plant spacing and land preparation in terms of crop yield. Increases from 40 to 100% over traditional yields are being achieved.

Our hydrologists have developed methodologies for using variable limited data generated in developing countries to estimate irrigation requirements. Government agencies in Colombia, Ecuador, all of Central America, Panama and Venezuela now have staff sufficiently trained to be able to use the method as a basis for planning and scheduling water use.

Four types of drains - open, closed concrete, perforated plastic and mole have been installed in Colombia, El Salvador and on the USU drainage farm. Criteria for their use, especially in heavy and volcanic ash soils under multiple cropping conditions have been developed. These criteria are now being used in Colombia and El Salvador.

Results from our studies on methods of water application have shown that drip irrigation is an effective method for applying limited amounts of water to relatively heavy and impermeable soils. In El Salvador it resulted in the use of 90% less water than furrow irrigation when used on volcanic soils.

In Brazil, our staff has directed the planning and implementation of the irrigation components on three new agricultural research stations in the Sao Francisco Valley at Pirapora, Formoso and Barreiras. The Pirapora station is now able to function effectively under local professional direction.

In optimizing the use of a limited amount of irrigation water on the heavy Malambito area soils of Colombia, it was found that the soils were highly variable as were the crop yields. The cause was a combination of minor element deficiencies, and excessive shallow tillage. Minimum tillage and subsoiling greatly improved production. Soy beans were found better adapted to the heavy soils than the common crops of the area.

Poor water infiltration has been overcome in Chile by development of specifications for incorporating crop residue into the soil surface. In Colombia, through a series of leaching experiments, we have shown that saline soils of the north coast can be improved economically.

A computerized hydrologic simulation model has been developed which provides irrigation project directors with a method for forecasting the effect of alternative land use decisions on the elevation of the ground water table. It is being utilized in Colombia on a pilot project.

Economic research results to date indicate: improved on-farm water management and availability show very renumerative returns; we have found ways for even small farmers to participate in these benefits. For example, supplying portable pumps or creating property easements for small channels to reach surface water supplies would greatly enhance the incomes of hundreds of small rice farmers in Ecuador. The dairy farmers of Sonsonate, El Salvador could get adequate supplemental irrigation from underground supplies at much lower cost than they will bear with a proposed surface project.

The law program's research has identified laws in the Andean Pact Countries which are constraints and facilitators to improved on farm water management. A water law digest and comparative study is being published and articles are being authored focusing on these factors. This information has been used in Ecuador, Colombia and Bolivia in drafting new legislation.

GENERAL BACKGROUND

It is estimated that over 200 million hectares of land are presently being irrigated in the world. The annual rate of increase is about 2 1/2 percent or 5 million hectares per year. There are over 500 million hectares of potentially irrigable land in different countries of the world.

In Latin America approximately 7.8 million hectares are being irrigated. The various governments report that they have definite plans to increase this acreage to about 16 million hectares in order to help meet their increasing domestic food requirements, develop export potential and provide employment opportunities for rural workers.

The irrigation technology developed in the United States and elsewhere cannot be transferred to an LDC without, in many cases, considerable modification. Indeed, in many situations, no appropriate technology exists to transfer. Historical development--laws--customs--are different. Soils and climate in the tropics are different. Labor and machinery costs are different. Everything from institutional structure to insect metabolism demands unique solutions in each LDC. However, methods for studying and evaluating problems are transferable.

AID, recognizing the opportunities to assist in on-farm water management, and being aware of Utah State University's historical interest in Latin America, entered into a contract with U.S.U. in June 1968 to provide assistance in on-farm water management research using Latin America as the primary research area.

The contract specifies general and specific objectives. However, it does not describe exactly where the actual work is to take place nor the investment to be made in each program nor the priorities between programs. These questions have been dealt with by negotiation between the contractor, USAID missions, national irrigation research agencies and AID's Technical Assistance Bureau in Washington as opportunities to dovetail mission and national priorities with the contract objectives have been identified.

In addition to identifying priority topics for research, it has been necessary to develop an approach, or way of organizing the program. Over the four years of the contract, three closely related but distinct components have become well defined. These are:

1. Identifying programs which directly relate to the specific contract objectives
2. Carrying out the research and analyzing the results
3. Transferring the results to users.

One of the many interesting problems related to the contract is determining what percentage of the resources made available by AID to allocate to each component.

The contractor has tried to be alert to the needs and attitudes of AID and collaborating national agencies and strike an "acceptable" balance. In general, although all the components are taking place simultaneously, the first year emphasized program identification, the following three, program execution and the fifth year, technology transfer.

PROJECT OBJECTIVES

As stated in the contract, "The general objective of this research is to increase food production in the arid and sub-humid lands of the less developed countries through the improvement of water management practices and the integration of those with other good management and cultural procedures. The research under this contract will be aimed at water management problems in the semi-arid lands of the Latin American region but will be applicable in principle to similar conditions in other regions. This improvement of water management practices is necessary to obtain maximum economic returns from limited water resources and such inputs as improved seeds, increased use of fertilizers and pesticides, and supporting institutional structure.

SPECIFIC OBJECTIVES

The specific research studies will be selected to meet the high priority needs of the Latin American area. These studies will include but not be limited to:

1. The development of knowledge and data on how best to conserve and utilize water falling on the land as rain and the most efficient means of supplementing needed soil moisture by a limited amount of irrigation water.

2. The development of knowledge and data that can be used for the economic design and construction of water conveyance and delivery systems including structures for control and measurement of irrigation water especially on the farm.

3. The development of surface and sub-surface water removal systems to eliminate the hazards resulting from surface flooding and high water tables.

4. The identification of important factors to be considered in land preparation and leveling of the various soils in the major climatic zones and the relationship of these factors to water management, erosion, water infiltration, and good land use and cropping practices.

5. The development and adaptation of methods of water application, including time and amounts, which are suitable and efficient for different soils of varying physical properties (water-holding capacities, intake rates, etc.) with major crops.

6. The integration of these water-use factors into a productive cropping system consistent with farm size and available farming practices.

7. Where soil, water quality, salinity and exchangeable sodium are problems, studies will include soil amendments, soil and water management procedures and use of salt-tolerant crops.

8. The identification of institutional factors - (legal, social, economic, religious, manpower, credit etc.) that influence the efficient distribution, management and utilization of water at the farm level."

Continued Relevance of Objectives

As already described in the third annual progress report, (41)*

"Since the date of signing of the contract in June 1968, several developments have caused some modifications in the orientation and emphasis of the work.

It is evident from the wording of the contract and from verbal and written communications with AID/Washington that USU's re-

* Bracketed numbers refer to publications listed in Appendix A

search activities must be carried out by mutual agreement with the host country agricultural research agencies and USAID missions.

Subsequent to the drawing up of the original contract, USAID mission activities in Venezuela were phased out. Except for the water requirements component, contract activities were accordingly transferred to other countries.

USU developed during the first eighteen months of the contract plans of work, and these were mutually agreed to by appropriate host country agencies and USAID missions. The first plan was verbally arranged between the Chilean Ministry of Agriculture, USAID/Chile and USU. It emphasized efficient utilization of water under severe drought conditions. After several months, when a severe drought terminated, the program emphasis changed to water-fertilizer interaction on corn to be carried out with Department of Agriculture researchers in the Aconcagua Valley near the City of Los Andes. Subsequently other written agreements were arranged with the governments and USAID missions of Brazil, Colombia, Ecuador and El Salvador. These appear as Appendices B through F of the Second Annual Progress Report. (40)

It is of importance to those reviewing this contract to understand that USU can involve itself in only those activities which the USAID missions and host agencies agree are important to the current needs of the country. This is the overriding constraint. Even the work being carried out primarily at Utah State University is supporting the agreed upon field activities.

A component not originally referred to in the contract but which AID, specifically requested be included, is the economic evaluation of the impact of irrigation and irrigation research in the Latin American countries. This was therefore added to the original work plan.

The original contract objectives are still relevant. All are not receiving equal emphasis as will be evident in this report."

During the current reporting period the Chilean water fertilizer - interaction studies reached an end point and Professors Kern Stutler and Don Kidman were transferred to El Salvador. Professor Richard E. Griffin returned from El Salvador to Logan upon completion of his two year assignment.

Previous progress reports have listed accomplishments under program headings using a series of code designations from PO1 to PO8. For example,

the PO5 Program was "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."

In order to aid those reviewing this report to relate the activities and accomplishments to the specific objectives as listed in the contract documents the format has been altered by describing accomplishments under the headings of the specific contract objectives.

The prefix (i.e. I-C(1)) which appears immediately before the "specific objective" statement refers to the section in the contract where the objective is specified.

I-C (1).

The development of knowledge and data on how best to conserve and utilize water falling on the land as rain and the most efficient means of supplementing needed soil moisture by a limited amount of irrigation water.

Accomplishments to Date

Work commenced on this objective in 1969 when the contractor located Dr. Ray Miller in Venezuela through a joint agreement of USAID/Venezuela, the Ministry of Public Works (MOP) and the OAS. He was located at the MOP agricultural research station at Guanare. Shortly after his arrival, USAID closed out their Rural Development office and the contract's financial support of Dr. Miller's activities was accordingly terminated. However, partial credit can be taken by the contract for the work accomplished by him and his Venezuelan counterparts which has been reported in the annual reports of the Ministry of Public Works and eight technical reports authored by Dr. Miller. (See listing in Appendix A (56-62).

These reports include descriptions of using supplemental irrigation to germinate corn and beans so they could be planted prior to the rainy season.

A. Pirapora, Brazil

At the Pirapora project in Brazil's Sao Francisco Valley, several tomato plots were provided with supplementary irrigation during what is normally

known as the rainy season. These plots produced above average yields while those not irrigated were a total failure because of water stress.

B. Aconcagua Valley, Chile

Early efforts by our researchers in Chile were directed toward water use strategies under drought conditions. This demonstrated the use of deep soils to store moisture. Later, the Chilean collaborators became more interested in water-fertilizer interaction when a 3-year drought was broken.

I-C (2).

The development of knowledge and data that can be used for the economic design and construction of water conveyance and delivery systems including structures for control and measurement of irrigation water, especially on the farm.

Accomplishments to Date

A. Bolivia

A report entitled "Irrigation Analysis for Selected Crops, Santa Cruz, Bolivia" and its Spanish version "Estudio de Riego Por Cultivos Seleccionados, Santa Cruz, Bolivia" was prepared under USAID/Bolivia contract. The portion of the report dealing with irrigation requirements was based on data collected and analyzed under this contract. (14)

A country-wide analysis of water differences and moisture availability in Bolivia was prepared. It was used by the British Technical Mission in Tropical Agriculture in preparing a country wide "Land Systems Survey" which relates soils, geology, climate, vegetative cover and elevation to agricultural suitability and crop adaptation.

B. Brazil

SUVALE-- (The Sao Francisco River Development Agency is the agency of the Ministry of the Interior responsible for designing and implementing a program of development of the river basin. They are heavily committed

to the agricultural development of the valley. As part of their strategy, they are developing demonstration, training, and research stations (CTI's) at strategic locations.

USU was asked to help develop the irrigation components of three stations located at Barreiras, Formoso and Pirapora. A very considerable amount of the time of the field staff, Professors Norris Gilbert and Lloyd Austin and USU backstopping staff, especially Professor Rex Nielson, has been devoted to working closely with SUVALE administrators in the planning, design and layout of these stations. Most of the actual research activities could not be implemented until the stations had been physically developed.

1. Pirapora

At this research station in the Sao Francisco Valley the USU team consisting of Prof. Norris Gilbert and Lloyd Austin were heavily involved from April of 1971 until April of 1972. During this period the team assisted with both sprinkler and furrow irrigation installations, acquiring through USU a number of gates for gated pipe. These were used for furrow irrigation and readily accepted by the station personnel. They assisted in redesigning the irrigation canals to provide a more economic and practical installation than had originally been contemplated by the Brazilian engineers. Prof. Austin designed a number of portable checks which are now in use in the canals to control water levels and facilitate the use of siphons. He cooperated in drafting and developing the design of an underground pipeline for one of the six three-hectare fields and a water distribution system for the undeveloped portion of the station. A water holding reservoir, first recommended by the USU team has been constructed and is in use. With some minor exceptions, practically all of the USU recommendations made in its original survey in 1969 and by the present USU team have been followed at Pirapora.

2. Formoso

The major activity at this station has been in its physical development, much of which has followed the recommendations made by the USU team in September, 1969. Pipelines and canals were repaired, new lateral canals constructed, a large building for laboratory, office space, repair, equipment and seed storage was built--several homes were built

for Brazilian technicians and their families. Completion of construction of the water distribution system came too late for any furrow irrigated plot research during the 1972 dry season.

3. Barreiras

At the beginning of the report period, the station water distribution system had been completed and some actual irrigation done, including furrow and infiltration tests. Since then, a great deal of development work has been done on the station and it is now physically ready to be used intensively for field research. Improvements include the following:

Completion of a building to house office, laboratory, repair shop, and storage of equipment, seed and supplies.

Installation of two electrical generators to supply energy for the facilities.

Reconstruction of pumphouse and installation of second diesel pump increasing capacity of irrigation system from 35 to 70 liters per second.

Installation of laboratory equipment for soil moisture determinations. Concrete slab 12 X 20 meters constructed adjacent to office for use in threshing and drying crops.

Station drainage structures installed and drainage ways grassed over.

Groundwater stage observation wells installed as recommended by USU and USBR teams.

Dormitory classroom and other housing facilities under construction for the irrigator training program.

The land in the original station, along with an adjacent area of 7 hectares was purchased by SUVALE. The additional land will be used for irrigator training and demonstration purposes.

A water reservoir, canal and ditches are already under construction and leveling operations complete on this newly acquired land.

The USU team assisted with the irrigation including operation and maintenance of the canals, tests to determine the rate-of-advance curves for furrow irrigation, and infiltration and soil moisture tests for determining when and how long to irrigate. Suggestions have also been given on how to improve the drainage system and overall efficiency of the irrigation system.

4. Small Irrigation Projects

SUVALE has begun the promotion of a number of small irrigation projects on private farms. The USU and USBR teams have contributed their expertese in assistance and planning and activating these projects. The USU team is particularly involved in two projects to date, at Barreiras and at Bom Jesus da Lapa. The team may become involved in additional small irrigation projects in the coming months.

Interpretation of Data

The major thrust of activities has been to assist the technicians of SUVALE to set up and begin to operate three research stations in the Sao Francisco Valley. A number of "classic" obstacles have had to be dealt with:

- Poor infrastructure, especially lack of adequate communication systems between field and headquarters.
- Lack of trained counterpart staff
- Virgin land to be cleared and leveled
- Water distribution systems to be built
- Buildings to be built
- Machinery, seeds, chemicals to be acquired

These were all more or less expected problems and staff directed most of their energies toward assisting the SUVALE technicians in the many problems incident to getting stations established where previously there was practically nothing.

One obstacle which was beyond the terms of reference of the team but which has a direct bearing on the present and future progress of the SUVALE research stations is related to priorities set by SUVALE management. Currently so much of their energies are directed towards development of new lands, relocating people, building irrigation projects, etc., that there is insufficient left over to mount an effective agricultural research program. It appears that the strategy is for SUVALE to phase itself almost completely out of research and rely on others such as the Ministry of Agriculture and in some instances contractors to carry out the needed research. USU is watching this situation closely to determine whether a realignment of its working arrangements will better serve the needs of the country and AID.

A very high level of interest has developed among researchers in the Ministries of Agriculture and of the Interior in developing a program to determine crop water requirements. A new agreement incorporating research and training in this subject area is presently being negotiated with the Ministry of Agriculture, USAID/Brazil and the contractor.

In anticipation of this agreement a preliminary analysis of climatological data from over one hundred stations in the north-east has been completed.

The contractor has been invited to participate in a National Ground Water Symposium sponsored by the University of Sao Paulo, Engineering School of Sao Carlos. Professor Hargreaves will represent USU by giving two papers related to crop water requirements. Their titles are:

"Irrigation Requirements and Ground Water Development" (18)

"Economic Aspects of Irrigation from Ground Water" (28)

C. Chile

A Chilean graduate student, Juan Tosso, finished under Christiansen and Hargreaves supervision, his Master's Thesis entitled "Analysis of Chilean Meteorological Data to Estimate Evapotranspiration and Irrigation Requirements." (7)

D. Ecuador

The analysis of climatic and evaporation data for Ecuador was continued using an additional year of data. Because of the short duration of much of the available data, the extra year was considered important. One more year of data, soon to be available, will be included in the final report which is now in the process of being prepared.

The study can be summarized in four major parts:

1. The development of the formulas and equations to estimate pan evaporation from available climatic data.

2. The relationship between pan evaporation and potential evapotranspiration which has been developed previously from studies in the United States and many other countries.

3. The determination of effective precipitation by the Gamma Distribution Probability Analysis from long time precipitation data.

4. The computation of moisture deficiencies and moisture availability indices from a combination of items 1, 2, and 3 for some 126 stations in Ecuador.

A report on evapotranspiration studies was made by Engineer Jose Yepez of INERHI after his visit to Logan in 1971. He used procedures developed by Christiansen and Hargreaves, and while in Logan was assisted by Richard Conn.

A computer report on the Ecuadorian studies is to be prepared.

E. Venezuela

A Venezuelan student, Freddy F. Rondon, was assisted in his Master's Thesis Study, "Estimation of Irrigation Requirements for Venezuela," by his major professor, Jerald E. Christiansen. (8)

Studies Outside of Latin America

In order to evaluate the generality of the Christiansen-Hargreaves' equations, special attention was given to their application on data collected from Iran and Pakistan.

Two Iranian students, Hossein Mirnizami and Reza Khosravi prepared, under their supervision a Master's Theses on "The Relationship Between the Climate and Dry Farmed Wheat in Iran" and "Pan Evaporation and Evapotranspiration in Iran." (9) & (10)

A review of climatic data from Pakistan (provided by Colorado State University) was made. Results compared closely with those from Latin America.

Further analyses were made of evapotranspiration-climatic relationships using data from California, Ohio, Australia, Venezuela, Israel and other locations.

Crop coefficient data was reviewed and an updated, improved tabulation of crop moisture use coefficients has been prepared.

A technical paper "Evaluation of Water Deficiencies" was prepared and presented at the American Society of Civil Engineers, Irrigation and Drainage Specialty Conference, Spokane, Washington, September 26, 28. This paper was published in the "Age of Changing Priorities for Land and Water" pp 273-240 published by the ASCE.

Three publications were completed during the year and printed by the U.N. which made use of analyzed data under this contract. (11)

Because of the high involvement of a number of national and international agencies in research and use of climatological data for agricultural purposes, the contractor's researchers, Professors Jerald E. Christiansen and George H. Hargreaves and several USU graduate students have written a number of papers in collaboration with these agencies. See Appendix A.

I-C (3).

The development of surface and sub-surface water removal systems to eliminate the hazards resulting from surface flooding and high water tables.

Accomplishments to date

A. El Salvador

Observation wells were dug at the Ministry of Agriculture's demonstration farm in the Zapotitan Valley. It was noted that the water table fluctuated between 35 and 70 cm. below the ground surface. USU purchased and sent to El Salvador 210 meters of plastic drain pipe. Immediately after installation, the water table dropped from 70 to 180 cm. During the rainy season it rose to about 140 cm.

1. Interpretation of Data

The whole lower portion of the Zapotian Valley has a high water table in spite of the highly porous volcanic ash soil. It is not yet clear what causes

the high water table in this region. However, the installation of the perforated 4 inch diameter plastic drain pipe at an average depth of 1.80 meter to crown has shown the El Salvador researchers a better economic alternative for lowering the water table below the root zone than their previous method of open drains. Because of poor soil stability, open drains have required considerable maintenance and use up excessive amount of land.

B. Colombia

Six buried drainage lines have been completed in a 16 hectare study area. One hundred and twenty observation wells and seven batteries of piezometers of four tubes each have been installed to evaluate the effect of the drains. Flow and electrical conductivity measurements have been made weekly on the discharge from each line.

Water levels which were initially about 50 cm below the ground surface dropped immediately after installation of the drains. Initially high salinity concentrations in the water have over the past four months also dropped appreciably.

A major component of this study is to determine methods of reclaiming soils seriously affected by high concentrations of salt. An area of study in the light soil zones was selected outside the zone of study for the buried drains. The soils in this area are so affected by salts that only the hardiest of salt tolerant native vegetation will grow. Most of the area in the dry season is white on the surface. To obtain drainage for leaching experiments, a site was selected which is bisected by a large open drain. The study consists of two rows of sixteen plots, five by five meters parallel to and on both sides of the open drain. Eight of the plots have had an application of gypsum. An additional eight have received no chemical amendments. Of each of these sets of eight plots, four have had the surface left in the natural condition while the remainder were disturbed with hand tools to loosen up the surface. Eleven observation wells and six piezometer batteries of four tubes each were installed to monitor daily the ground water movement.

Results of the soil analyses are not yet available. There are, however, visual signs of leaching effects. All of the sixteen plots in the first portion of the study area, except the four which did not have gypsum and had the surface soil disturbed, show similar results. The soil structure is now loose and friable and there is luxuriant weed growth of a variety not found in the salty areas around the study zone. The remaining four plots are essentially still barren except in the corners of two that are beginning to show signs of improved soil structure and weed growth. At this time, the leaching process is apparently just as effective on areas having native vegetation intact and no gypsum added, as it is on areas having the gypsum amendment.

It is intended that upland rice will be planted in the sixteen leached plots to determine the effects of leaching on a growing plant. Six additional unleached test plots will be seeded for comparison of growth.

The drainage system will continue to be monitored and the data analyzed. The physical characteristics of the sub-soil are being determined. The leaching study will continue. Soil retention curves and textural analyses for representative soils in all study areas are being secured from a local soil physics laboratory.

Dissemination and utilization of research results

Results accumulated to date are being made available to ICA and INCORA through daily contact during the conduct of the experiments. Other involved agencies will also have access to data and the conclusions being obtained. Extension pamphlets and field days are being considered as a means of dissemination to the area land holders. Several research papers will be prepared.

C. Utah

Mole Plows

In regions where several crops are produced each year from the same land (multiple cropping) it is very important for farmers to get on the land as soon as possible after the rainy season in order to prepare and seed it. Where land is poorly drained naturally, the installation of mole drains can

hasten the process, often to the point of adding an additional crop each year. Moreover it can improve yields by lowering the moisture content in the top thirty inches from saturation to field capacity. Under some circumstances, mole drains are useful where leaching to control salinity in the crop root zone is desirable.

In order to install useful, economic mole drains a number of parameters must be taken into consideration. This program is

- Comparing the relative effectiveness of several sizes and shapes of mole plows including a comparative study of double vs. single mole plows.
- Determining the durability of mole channels
- Evaluating their effectiveness in removing water at various spacings and soil types
- Evaluating the efficiency of a combined mole-pipe drainage system
- Determining power requirements for installing mole drains
- Determining soil moisture content range for mole drain construction.
- Determining the effect of soil resistance on shape of mole plow and plowing speed.

Activities

1. Eight double-mole and two single-mole plows have been designed, fabricated, and tested. Two field studies were conducted on a 17-acre field at USU in which mole drains have been constructed with a single-and double-mole plows and a qualitative evaluation on the durability of mole drains was carried out.

2. The effectiveness of the drains on removing salts was investigated.

3. Laboratory studies were completed and results presented as three M. S. theses at Utah State University.

4. Tentative field studies on the power requirement for pulling a mole plow were made in the summer of 1971. In the summer of 1972 a combined mole pipe drainage system was constructed in a 2 1/2 acre field on the USU Drainage Farm. The results of this investigation will also be presented in two M.S. theses at the end of the academic year, 1972-73.

Accomplishments to Date

1. According to laboratory model studies double mole channels are more durable than single mole. After three years of operation on the USU drainage farm, most of the double mole channels are still functioning. After another year's observation a progress report will indicate more quantitatively the relative advantage of the double mole. (21)

2. The most durable, smooth channels are produced when soil is about at its field (water) capacity. (21)

3. Power requirements vary inversely with soil moisture content. In the USU drainage farm soils, (heterogeneous clay loam) the resisting force at 28% moisture (field capacity is about 25%) was about 140 lb. whereas at 20% it was about 330 lb. Although the relationship is not quite a straight line we can say that for the soil in the experimental field, power requirements are increased by about 29% for every one percent decrease in soil moisture in the stated range. Beyond this moisture range there was a much diminished effect on the rate of change of power requirements. (22)

Equations have been developed to enable a contractor to determine the size of tractor required for various soils and moisture contents. (22)

4. Considerable reduction in electrical conductivity (salt content) was found in the soil samples taken from the mole drained area. (19)

5. A one hectare field at the research station at Tibaitata, Colombia was mole plowed in 1971, then planted to corn. Although a change in national

priorities did not permit quantitative results to be gathered, visual observation during a visit by our Professor Embry when the corn was approaching maturity indicated when compared with an adjacent corn field, a significantly heavier yield. This was attributed to better drainage hence more aeration during the early growth stages.

6. Results of work done in 1972 (19) (25) indicate that mole drains, when used in combination with tile drains in heavy soils lower the water table much faster than when tile drains alone were used. This is a particularly desirable feature for heavy soils in tropical areas subject to frequent rains.

7. Under Utah labor and equipment rental conditions, the cost of mole drains spaced 6 feet apart is about $10.00 per acre per year assuming a 3 year life for the drains. (19)

8. Seventeen acres at the USU drainage farm was unproductive prior to the beginning of the tests. It is now used for growing grain.

I-C (4).

The identification of important factors to be considered in land preparation and leveling of the various irrigated soils in the major climatic zones and the relationship of these factors to water management, erosion, water infiltration, and good land use and cropping practices.

A. Chile

In an experiment designed to determine whether water intake could be improved through management of the soil various amounts of crop residues were plowed into the soil. Plowing in 110 quintales per hectare of the previous year's corn stalks resulted in a 38 percent increase in yield. This increase is attributed to the improved ability of the soil to accept and store water. (53)

B. Colombia

In the Atlantico 3 Irrigation Project, a 400 hectare citrus orchard showed highly variable yield results. Our investigation has established that a major cause of the yield variability has been caused by inadequate levelling of the land prior to planting the trees. It was decided, when the orchard was originally planned (about 1965) that it would be more economical and less likely to adversely affect soil fertility to irrigate by sprinkling rather than level the land and flood or furrow irrigate. Unfortunately, although the topography of the site appears to be fairly flat, it is in fact characterized by a number of shallow, isolated depressions. Since infiltration is not high in this area, water (both rain and irrigation) tends to run off the high spots and collect in the depressions. Leaching is taking place in these depressions whereas salt is "wicking up" in the high spots, making these areas even less permeable.

This problem is now well understood by the farmers and the Colombian Researchers. It is hoped that the results of the leaching experiments described under objective I-C (7) will find a direct application in resolving this particular problem.

An "artificial" topography was created in this same orchard when open drains were constructed running more or less at right angles to the slope of the land. Banks were built up on both sides of the drains. During the rainy season this creates some surface ponding against the uphill side of the drains. It has been pointed out that this partly defeats the purpose of the drains. The farmers have accordingly opened several surface drains through the uphill bank.

1. Dissemination of Results

This situation has received considerable publicity throughout the country, especially among the professionals of the Ministry of Agriculture's Agrarian Reform Agency (INCORA) and their research agency (ICA). It has provided a classic example of the need to understand both the topography and class of soil before designing an irrigation system. Reference will be made to this when the results of the leaching experiments are reported.

I-C (5).

The development and adaptation of methods of water application, including time and amounts, which are suitable and efficient for different soils of varying physical properties (water-holding capacities, intake rates, etc.) with major crops.

Accomplishments to Date

A. Chile: Resume of Previous Years' Activities

At the beginning of the 1969-70 growing season, Professor Kidman from USU, in collaboration with the Chilean Agricultural Research agency at La Platina and the Catholic University of Valparaiso set up two research and four research and demonstration plots on farms in the Aconcagua Valley, north of Santiago.

During the 1969-70 season, two corn varieties were tested together with nitrogen and plant population components. The variety Tracy 133, was consistently better than others tested at a population density of 90,000 plants per hectare. Significant responses to nitrogen and to high water application rates were noted. (54)

During the 1970-71 crop year, the objectives were:

1) To test the effects of two soil moisture levels, five nitrogen fertilizer rates, and two plant populations on the yield of shelled corn.

2) To correlate evaporation of water with irrigation water requirements of corn.

3) To compare effect on corn yield of two methods of seed bed preparation.

Results indicated that at 200 kilograms per hectare of nitrogen, and adequate water, production increased from 45 to 90 quintales per hectare (68 to 135 bu/ac.) on the demonstration plots. On the research plots yields of up to 106 qq/Ha. (160bu/ac.) were obtained but there was little response to nitrogen variation. This was due to a high ambient nitrogen level in the soil on the plots

made available for the experiments. There was an increase of yield of about 50% between the two irrigation levels of 58 cm vs. 83 cm averaged over the two stations, in favor of the 83 cm irrigation level.

Data relating evaporation as measured with a pan to irrigation water requirements were inconclusive. There were no significant differences in yield for the two methods of seed bed preparation.

Results for 1971-72

Only one research farm was available. On this farm, 5 nitrogen rates to 400kg/ha, five plant populations ranging from 50 to 110 thousand plants per hectare, two varieties - hybrid MA-7 and Tracy hybrid T-133 were used. Irrigation was supplied uniformly to all plots.

There was a very significant variation in the plant population - nitrogen effect.

Maximum production resulted using variety Tracy T-133, 65,000 plants per hectare and 300 kg of nitrogen per hectare.

Dissemination and Utilization of Research Results

Complementing the above described corn plot research in Chile, a demonstration experiment was designed and used as a cooperative effort between INIA (Instituo Nacional de Investigaciones Agropecuarias), SAG (Servicio Agricola y Ganadero), and Utah State University.

1) To demonstrate to the farmers in the Aconcagua Valley, soil, water and crop management techniques that were validated by the experimental plots.
2) To train extension personnel in designing, conducting and applying field demonstration type experiments.
3) To obtain supplemental information from which production management recommendations could be more clearly defined within the area.

Ten locations were selected on cooperative farms in the region. On each farm, plots were set out having as their variables, nitrogen application rate and plant population density. Seed bed preparation and irrigation methods were held uniform through the plots but conformed to the results for the high-

est yield as indicated in the research plots. The remainder of each farm was intended to serve as the control.

A high level of interest developed among the communal farmers and most of the cultural practices introduced were soon incorporated into the rest of the farm operations.

In order to extend the benefits of these experiments beyond the farms on which they were conducted, four tours were organized by the San Felipe Services (SAG) office. Forty farmers from 25 different farms participated together with a number of extension officers from other regions. On the farms where the demonstrations were conducted, an average increase in overall corn production of 100% has since been reported.

Most of the day to day indigenous support was carried out by a team of five professionals and nine technicians. They became proficient in experimental plot layout, fertilizer application, improved seed bed preparation, calibration and adjusting planting equipment, furrow-irrigation, and experimental plot harvest techniques.

With the experience acquired from this year's work, the SAG personnel should be able to continue this type of program.

Professors Stutler and Kidman were ably assisted by several timely visits of Professor David James from the Department of Soils and Biometeorology who assisted in the design of the plots and the analysis of the results. USU staff left in June 1972 at the end of the harvest period. It is expected that they will be invited to return on short follow-up visits to advise the SAG professionals who, it is believed, plan to carry on with the experimental and demonstration work.

Accomplishments to Date

B. Colombia

The Colombian Agrarian Institute (ICA) established its agricultural engineering program on their Malambito research station on the Agrarian Reform Institute's (INCORA) Atlantico 3 project near the city of Barranquilla in late October of 1971.

A major objective is to conduct field research in water management on heavy soils typical of those throughout the southern section of the project. Progress in establishing the program has been made in several areas during the past year including the designation of field space and physical facilities by INCORA officials and the accumulation of equipment necessary for field plot research. L ling of a one hectare field suitable for studies utilizing furrow irrigation was completed. In April, six ICA personnel were appointed to the project. Two of these appointed, Mr. Alvaro Castano and Mr. Alfonso Lara, agricultural technicians have since assumed responsibilities for supervising the field work and management of the meteorological station. Mr. William Rubink, candidate for the MS degree in Soils at USU, arrived in late August. His program involves intensive sampling of the heavy soils for both chemical and physical analyses and should contribute greatly to future agricultural research in the district.

Considerable characterization of the soils has taken place utilizing ICA laboratories at Palmire and Turipaná and the INCORA laboratory at El Limon. One of the main reasons this area was selected was because of poor growth within the region; this has been attributed in the past to salinity, water logging, and low fertility as a result of constant leaching in low spots and highly localized soil acidity resulting from the degradation of sodic soils. Field observations and recent analyses of the soil so far fail to identify the causes of poor growth.

1. Sesame

A field test for the purpose of comparing the response of Sesame to various combinations of nitrogen and phosphorous under irrigated and dry land conditions was initiated in November, 1971. The only statistically significant variable was phosphorous. Application of phosphorous resulted in significant decreases in both height and yield from 594 to 544 kg/ha on the plots treated with 50 kg/ha of P_2O_5.

Sesame throughout the test area developed a chlorosis shortly after 50 centimeters of plant height had been obtained. The symptom remained until

flowering was initiated. Tissue analyses of both normal and chlorotic leaves indicated that manganese was deficient so on several test plots solutions containing varying amounts of manganese, iron, zinc, and magnesium were applied after plants had reached approximately 50 centimeters in height. Application was made directly to the leaves. Foliar treatments with manganese at all rates resulted in development of a more intense green color by sesame within two weeks after the applications were made. Addition of a surfactant to the solution seemed to amplify this effect. The chlorosis became apparent again after three weeks following the production of new leaves. No significant increase in fresh weights over those of the controls were found as a result of the foliar treatments with trace elements. It was evident that phosphate fertilizer aggravated the manganese deficiences and that earlier treatment with manganese would be desireable.

2. Soy Beans

A water-fertility interaction study involving ICA Taroa soy beans was initiated in January, 1972. Field plots were arranged according to a split-split plot design. Moisture levels were varied during podfill of main plots with the control and nitrogen at rates of 50, 100, and 150 kg/ha as subplots. Phosphorous was applied as P_2O_5 at 100 kg/ha. Moisture levels were controlled with tensiometers from a soil depth of 12 inches. A maximum production was realized at 1105 kg/ha for the maximum water and fertilizer treatments, i.e., 22 centimeters of water and 150 kg/ha of nitrogen.

3. Corn

A field test with H207 corn was initiated in March, 1972 for the purpose of measuring the response of this variety to nitrogen and phosphorous treatments under differing water regimes on the heavy soils of Malambito. Scheduled irrigation treatments were not applied due to frequent heavy rains

during the period the experiments were in progress. Stand development was highly uneven in most areas of the experiment due to the presence of stunted and chlorotic plants which represented abrupt and extreme soil differences. Corn in four of the sub-lots was uniform, however, and considered normal in both height and appearance. Corn yields were found to be low in all of the treatments. Applications of 100 and 150 kg/ha of nitrogen resulted in significant decreases in grain from that harvested in control plots, i.e., from 1288 to 1016 kg/ha or a decrease of 21%. This may indicate a boron deficiency.

4. Sorghum

Use of sprinkler irrigation on the heavy soils of Malambito results in the first few centimeters of soil becoming saturated rapidly with further downward movement of water very slow. Subsequent drying of this upper layer is also rapid, usually occuring within 4 to 5 days after water has been applied. These observations, in addition to the incidence of root system retardation in sesame and other crops have led to speculation that a shallow hard pan may be general throughout the experiment station.

A field test was implemented in May 1972, to determine if subsoiling would increase sorghum yields. Since the heavy soils are frequently harrowed up to 6 or 8 times during seed bed preparation, disc treatments, consisting of zero, three and six times prior to subsoiling were also included. Fertilizer treatments were subdivided within the disk treatments. A-14 was the sorghum variety utilized for the tests.

Greater sorghum yields were obtained from plots where subsoiling had been accomplished than from control plots, the increase being from 2205 to 2682 kg/ha for an increase of 22%. Frequent harrowing resulted in poorer yields going from 2614 for the control to 2250 kg/ha yield on the plots where the disk had been used 6 times. Application of fertilizers generally resulted in decreased yields except in plots where the subsoiler had been utilized.

Interpretation of Data (Colombia)

Electrical conductivity measurements have not demonstrated the presence of salts in sufficient quantity to reduce crop production in any of the areas where field tests were conducted. Analyses of a limited number of samples indicate that both pH and electrical conductivity may increase radically at greater depths and in the transition zones between the heavy and light soils.

Heavy soils in the vicinity of Malambito are mottled with small, irregular areas ranging from 1 to several square meters in size. These areas collectively may account for as much as 30% of the total area in certain fields. Soy beans seem to tolerate this soil condition much better than corn, sesame, or sorghum. Affected areas generally can be associated with low spots where water collects but frequently also extend over higher terrain.

1. Sesame

The sesame plots receiving irrigation water appeared greener and more vigorous; however, reductions in yield from lodging may have masked any beneficial effects of applying water. Error introduced by extreme soil variation could account for the lack of measurable response to water or nitrogen. Banding of phosphorous may have produced a more acidic soil condition resulting in depressed growth and reduced yields. Sesame plants examined after lodging had occurred were found to have roots which extended only 10 to 15 centimeters in depth for plants over 1.5 meters in height. It is speculated that this has been caused by the formation of a hard pan through excessive machinery use.

2. Soy Beans

Significant increases in yield of plots receiving nitrogen as compared to control plots were found only where water had been applied on two dates instead of one.

A more precise interpretation of these data may be possible upon availability of soil moisture retention curves which are currently being developed. Although plants were stunted and yields depressed due to severe water stress, soy beans appear better adapted to the heavy soils of Malambito than other crops common to the area.

3. Corn

Low production can, in large part, be attributed to lack of ear or grain development by a high percentage of the plants which as mentioned may indicate a boron deficiency. No differences were found between the phosphorous and non-phosphorous treatments.

Native corn generally appears better adapted to the heavy soils of Malambito than H207.

4. Sorghum

The data indicates that inputs normally designed to increase yields may be limited by improper use of farm equipment. Minimum tillage should be evaluated as a means of increasing yields as well as decreasing production costs.

5. General

Due to consistently low yields obtained for several crops over a period of years, a large investment in leveling and drainage may be prohibitive. A logical alternative could be the production of rice which is generally better adapted to heavy compacted soils than other traditional crops of the zone and would be tolerant to frequent flooding following heavy rains. Inundated rice is considered unacceptable because of the need to lower water tables in the district. Upland rice, however, could be of value in certain regions of the project. A test area has been seeded with CICA-4 in order to observe whether or not this variety might be suitable for the production of upland rice in the heavy soils of Malambito.

Sodic soils have been reported as widespread throughout the southern sector of the district, although results of analyses of samples collected in the experiment station do not indicate the presence of sodic or saline areas. Heavy soils are of poor structure and characteristically shrink upon drying. A field study has been established to measure the response of cotton, corn, rice sesame, sorghum, soy beans, and tomatoes to lime and gypsum treatments.

Tests involving the response of corn to boron treatments and seasame to mangenese treatments are also in progress.

Soil heterogenity was reflected by irregular stands of some of the crops used for field experiments during the past year. Improved corn and sesame were found more sensitive to soil extremes than other crops tested as characterized by variable plant growth and trace element deficiency symptoms. Response to treatments of nitrogen or phosphorous by these two species was lacking or yields were reduced. Sorghum appeared only slightly better adapted to Malambito conditions than corn or sesame. Preliminary observations indicate that cotton is also intolerant to certain soil differences as evidenced by the widespread presence of both well developed and stunted plants within the same field. Soy bean growth was found highly uniform in two studies. A test currently in progress also suggests that upland rice is well adapted to the heavy soils. It is considered that farmers in irrigated areas with heavy soils equal to those of Malambito would have a greater probability of success through production of soy beans and upland rice than other crops mentioned. Such conjecture, however, should be supported by additional yield data. Emphasis will be placed on these two crops in future water and soil management research.

Accomplishments to Date

C. El Salvador

Water-fertilizer interaction experiments on corn were begun during the 1971 crop year at the "La Granja" demonstration farm in the Zapotitan Valley near San Salvador. Although no significant interactions were found, it was useful in developing criteria for the 1972 crop year.

A second corn trial, at a different site produced from 4500 to 5247 kg/ha. This is about 40% higher than the average high production for the country.

Because of limited water supplies and the need to minimize leaching out soil nutrients in a very porous soil it is important to use a minimal amount of water for irrigation. A trickle irrigation experiment has showed a saving of 90% in water used over furrow irrigation.

A graduate student developed and successfully tested a method for predicting the field performance of sprinklers for a variety of wind conditions. (50)

Dissemination and Utilization of Research Results

USU's Professor Richard E. Griffin worked very closely with counterparts from the Departments of Irrigation and Research (Direccion General de Obras, de Riego y Drenaje and Direccion General de Investigaciones y Extension Agropecuaria), of the Ministry of Agriculture. In addition he collaborated with staff of the Agricultural College (Escuela Nacional de Agricultura) at San Andres in preparing teaching materials and course outlines for extension students.

Professional staff of these institutions participated in the design and implementation of the research and thus became completely familiar with the techniques introduced.

Professor Griffin was assisted by Professor David James from the University's Department of Soils and Biometeorology who, through two visits during the period assisted in the design and evaluation of the research results.

Accomplishments to Date

D. Brazil

One water-fertilizer inter-action experiment was initiated during the year at the Barrieras experiment station using corn. Three irrigation levels and five fertilizer treatements were applied. Yield data are not as yet available.

1. Pirapora

An important activity was a trial to test the response of corn to residual effects of various tropical legumes used as green manure crops.
A number of variety trials were conducted. These included one on soy beans-yield range 1630 to 2966 kg/ha, one on rice-yield range 764 to 2964 kg/ha,

one on tomatoes yield range 16397 to 26,990 kg/ha, and one on sunflower-yield range 434 to 1525 kg/ha. In addition to the above experiments, a duplicate rice variety trial was planted at the same time but received no supplemental irrigation. During a rainless period in January the plants dried up, and although later revived by rains, they failed to yield much grain. A corn seed increase planting was made at the same time, half of which received supplemental irrigation during the drought period and yielded well. The un-irrigated portion yielded nothing.

2. Formoso

Some field trials and unreplicated observation plantings were conducted under sprinkler irrigation on the lower portion of the station where they could be reached with a small portable pumping system. Simple variety, spacing and date of planting trials were conducted. Crops included corn, cotton, beans, wheat, sorghum, rice, soy beans, alfalfa and okra. The USU team, at the request of the Brazilian technicians designed a water-fertilizer interaction trial that was to have been conducted under sprinkler irrigation during the past dry season. However, the limitations of the sprinkler system at the time did not permit the experiment to be run. It is planned to be conducted at a later time.

Gilbert reviewed field plans for the coming 12 months and suggested changes in the experimental designs to adapt them to furrow irrigation.

3. Barreiras

Experimental plantings during the rainy season occupied a very small proportion of the 9 hectares of field area including a national bean variety trial, a national corn variety trial, an unreplicated observation planting of rice, wheat and beans. Limited seed increase plantings of these crops were also made. A portion of the remaining area was planted to green manure crops, principally Canavalia. Some irrigation was applied to supplement rainfall but no data was collected on the effect of irrigation as compared to no irrigation. No fertilizers were applied.

During the May-October dry season, more extensive use was made of field areas including variety trials and observation plantings of water melons,

cow peas, and Irish potatoes. One field was prepared for planting citrus but the young trees were never delivered. Another field was prepared for a collection of forage grasses which did not get planted. All of the above mentioned plantings were harvested but the experimental data will not be available for statistical analysis for some time.

A water fertilizer interaction experiment was run on corn at three irrigation levels and five fertilizer treatments. Yield data is not available at this point.

Dissemination and Utilization of Research Results

Although no direct data in the sense of production yields has yet been produced or released by SUVALE, the USU team has collaborated with about two dozen SUVALE technicians who now have a good understanding of what it takes to organize research stations, get water to them and design water management experiments. Even though a number of these men have left SUVALE, they are still in the country and their experience is not lost to the nation.

The USU team was instrumental in promoting the attendance of 11 SUVALE technicians in a nine week course on Irrigation Practices sponsored by AID and conducted by USU's Department of Agricultural and Irrigation Engineering in Logan with visits to irrigation projects in most of the western states.

This program is scheduled to terminate in March 1973. At that time a final report will be prepared which will deal at some length with the problems of setting up new agricultural research stations.

I-C (6).

The integration of these water-use factors into a productive cropping system consistent with farm size and available farming practices.

Hydrologic Model Simulation

The third annual progress report describes the hydrologic modeling of the Atlantico 3 Project of Colombia using a hybrid computer. (41) The fundamental

objective of this study was to develop and test under field conditions a computer audit of the hydrologic system which might be used and applied in a general sense for managing water resource systems for the purpose of achieving specified goals related to agricultural production.

Accomplishments to Date

1. Input precipitation data were generated synthetically for a period of ten years. These data were generated on a basis of three years of available precipitation records at the Atlantico 3 site. The synthesized data were then applied in management studies involving the model.

2. A self calibration sub-routine was incorporated into the general program. This sub-routine uses a pattern search optimization technique for identification for the model parameters for a specific location. Thus, the general applicability of the model was considerably enhanced by the addition of this sub-routine.

3. A graphical plotting sub-routine was modified and added to the main program of the model. This sub-routine provides for the plotting of ground water level contours as computed or estimated by the model.

4. The model is now in working condition for examining, testing and evaluating various possible management alternatives within a given location.

Dissemination of Results

Various aspects of the model have been presented in papers prepared for presentation at professional meetings. The titles and resumes of these papers are included in Appendix A (33-37).

A seminar is scheduled to take place in Bogota in November to explain to officials of Colombian government agencies, (ICA and INCORA) the general structure of the model, including its capabilities and limitations and programming and operating techniques. Additional opportunities for display of the model have opened up in Costa Rica where the ARENAL project situated about 100 miles north of San Jose is interested in its use in connection with irrigation and hydroelectric power development.

Special Projects

In May, 1972 USU was asked by the USAID Missions in Guatemala and Panama to assist them respectively in:

1. Evaluating several problems related to irrigation and drainage on existing and proposed new lands for irrigation. (23)
2. Improving the irrigation component of a number of small community vegetable gardens. (38)

Professors Jerald Christiansen was sent down from Logan and E. C. Olsen from his post in Colombia to evaluate and recommend action. Reports were written and submitted to AID and the missions.

Recommendations were given to the Guatemala Ministry of Agriculture on

Ground water quality and methods of measuring ground water levels.

Surface water quality.

Drainage problems.

Irrigation needs.

Staff training for project operations.

The Panama Ministry of Health was advised on methods of determining water needs, drainage problems and system design methods.

I-C (7).

Where soil water quality, salinity and exchangeable sodium are problems, studies will include soil amendments, soil and water management procedures and use of salt-tolerant crops.

Accomplishment to Date

A. Chile

An irrigation water infiltration component was added this year because the previous years' work had shown the difficulty of completely wetting the root zone of the plots. (53)

It was concluded that:

1. Slow water infiltration is related to poor soil structure.

2. The problem has developed over the years as a result of the total removal of crop residues.
3. Water infiltration can be improved by incorporation of crop residues into the surface of the soil.

This problem should be investigated further to determine optimum amounts of crop residue, best methods of incorporation, and longitivity of the treatments.

I-C (8).

The identification of institutional factors (legal, social, economic, religious, manpower, credit, etc.) that influence the efficient distribution, management and utilization of water at the farm level.

A. Water Law Component

Dr. David R. Daines is the principal investigator for this program. He has been collecting data since the fall of 1970. Since January of 1971 he has been located in South America with his "home base" in Ecuador. His principal counterpart is Dr. Falconi the chief legal advisor of the Ecuadorian Institute of Hydraulic Resources (INERHI).

Activities Before Field Location

Prior to January 1971, an intensive review was carried out of data available from other institutions and individuals engaged in researching and improving water legislation and administration. These institutions included the Land Tenure Center at the University of Wisconsin, the United Nations section on Water Transport in New York, the United Nations Regional Economic Consult in Santiago, Chile and various individuals. A microfiche library consisting of about 30,000 pages was collected. The materials were obtained from various sources and include most of the subject matter from the Harvard Law Library.

Activities subsequent to January 1971

Work related to specific country needs

As part of Dr. Daines' assignment, he has been asked to provide advice

to several governments. In Ecuador, Dr. Daines advised INERHI on several drafts of changes in water law which were prepared for the Velasco Ibarra government and later the military government which assumed authority in March 1972. The last draft code was adopted in May of 1972. Dr. Daines supervised field studies carried out principally by D. Craig Anderson, a graduate student in Public Administration at USU. His research focused on irrigation water distribution organizations in Ecuador -- their methods of functioning -- the relationships between social, political, economic and physical factors to their operating programs. (64)

At the request of the Bolivian Ministry of Agriculture and the USAID/RRD Office, Dr. Daines prepared a review of a new water code that was being circulated among the government ministries. He prepared at the request of (INDERENA) Colombia and USAID/Colombia a portfolio of different legal and regulatory regimes related to water pollution control, subterranean water use and rights related to water.

Dr Daines is approaching completion of the research and preparation of the water law comparative digest for the Andean pact countries consisting of Chile, Bolivia, Peru, Ecuador, and Colombia. He has organized and outlined a methodology for describing the water law and administration systems so that they can be studied in a comparative summary context. (See Appendix B). The drafts, as they relate to the summary for each country, average around 60 pages per country, double-spaced. It is expected that the Ecuadorian Institute of Hydraulic Resources will assume responsibility for the final draft in Spanish through their Dr. Falconi. (63)

Dr. Daines was a contributing lecturer and participant in a conference on water planning held at Utah State University. In Valencia Spain, he made a study into the ancient and continuing water user distribution organizations in that area as background for the Spanish origins of Latin American water law. He also discussed cooperative programs between Utah State University and Colorado State University with their Mr. George Radosevich. In Rome, he reviewed the activities of FAO in the field of water legislation and explored possible areas of cooperation with that organization.

B. Economic Component

Accomplishments to Date

The main emphasis in the current plan of work has been on analysis and dissemination of collected data. Three reports were prepared during the spring of 1972 and forwarded to appropriate USAID mission personnel for review during May, June and July. Preliminary copies were desposited with TAB in Washington. Data on two additional field problems were collected in the spring and summer of 1972. Preliminary analyses of these latter studies were completed. One paper was read at the Western Agricultural Economic Association Meetings in July and two papers are under editorial consideration. These reports are listed in Appendix A (27, 29-32).

Findings

Small rice farmers in Ecuador's Guayas Basin can obtain high rates of return to simple and cheap water management investments. Such investments could easily be fostered by the central government with the result that real income and employment would be increased.

The rates of return to on-farm water investment in an established Guayas Basin irrigation project are very remunerative, especially for the smaller farmers. This not only provides some encouragement to complete additional phases of the project on the basis of costs and benefits but raises the hopes of more equalized distribution of rural income.

Irrigated pastures in Sonsonate, El Salvador, are beneficial to those dairy farmers who have adequate water. A proposed project to increase surface supplies will be more costly than the development of underground supplies through private pumping. Indeed, there may currently be adequate supplies from existing surface systems if canal management and headgate allocations could be improved.

At present, development of irrigation projects solely for benefit of sugar cane producers in the Santa Crus Area of Bolivia is economically questionable. There would be substantial transportation savings in relocating production areas nearer existing processing plants, but the savings could not offset the annual fertilizer and irrigation costs except for a surface system suitably

located near a river. Over the long run, pumping and surface irrigation would be economical if sugar cane is in rotation with other crops. Since less than 2,500 hectares need to be relocated near the miles, (to maintain necessary domestic cane production levels) in general water development program in the Santa Cruz area will almost certainly accomplish this result.

Interpretation of Data

Some have argued that the experience of years of technical assistance shows the need to provide farmers with a package of modern inputs if we are to induce technical change. Our research indicates that this point of view cannot be accepted without qualification. Situations must be evaluated on their own merits. In fact, not all parts of a modern package of inputs pay equally well even if benefits exceed total costs. For example, in the Latin American cases we have studied, better water supplies and irrigation management alone pay quite well but the returns to other inputs may not equal the cost of capital necessary for their purchase. Good returns to simple irrigation practices seem readily obtainable in diverse sub-humid or dry season areas. Thus, there appears to be good opportunity for on-farm water management research to have an important impact on large numbers of small farmers.

On the basis of the intensive project review of contract AID/csd 2167 conducted during January of 1972, some emphasis has been placed on more sophisticated analytical tools such as linear programming where the survey situation seems suitable. The conclusions of the sugar cane production alternatives report for Santa Cruz, Bolivia were based on such an approach. However, the main objective is to assist Agricultural Engineers and Agronomists to collect and interpret production function data based on water fertilizer and other crop input interactions. Such information is a fundamental aspect of any optimizing program for irrigation management and development in a given area. It is hoped that this emphasis can be effected shortly in the agronomic components reported in another program for El Salvador.

APPENDIX A

Publications Prepared

The following list describes publications prepared using resources provided by this contract. In most of the references cited other resources have been involved through data collection, assisting in the field research, actual publication of a report etc. In order to assist reviewers of this report in understanding the linkages generated at the reporting level, the following coding which appears at the end of each reference is provided.

(A) Data collected, report written and published using contract resources primarily.

(B) Report in Thesis form only. Student supervision by professional staff associated with the contract. Copies available on request.

(C) Report published using contract resources in which local water involved agencies collaborated.

(D) Report published by another agency. Data generated and analyzed by contract funds appears in the report.

Crop Water Requirements

1. A Study of Wind Velocity Profile at Santa Cruz Experiment Station, Venezuela. 1970. M.S. Thesis, Gutierrez, O. (B)

2. Analysis of Colombian Precipitation to Estimate Irrigation Requirements. 1971. M.S. Thesis, Hardee, J. E. (B)

3. Investigaciones Sobre Evapotranspiración y Requerimientos de Irrigación, (23 page report with 13 maps). 1970. Instituto Geographico Nacional (El Salvador C.A.) (D)

4. Irrigation Requirements in Latin American Countries. Second World Congress of Engineers and Architects, Tel Aviv, Israel. December, 1970. (Published in ITCO Review Vol 1, No 2 April 1972 pp 40-50), Christiansen, J. E., and Hargreaves, G. H. (C)

5. Analysis of Venezuelan Data to Compare Computed Evaporation, Potential Evapotranspiration and Evapotranspiration Deficit. 1970. M.S. Thesis, USU, Rujirakul, S. (B)

6. Estimation of Evaporation and Evapotranspiration in Colombia. 1970. M.S. Thesis, USU, Stutler, R. K. (B)

7. Analysis of Chilean Meteorological Data to Estimate Evapotranspiration and Irrigation Requirements. 1972. M.S. Thesis, USU, Tosso, J. (B)

8. Estimation of Irrigation Requirements for Venezuela. 1972. M.S. Thesis, USU, Rondon, F.F. (B)

9. The Relationship Between the Climate and Dry Farmed Wheat in Iran. 1972. M.S. Thesis, USU, Mirnizami, H. (B)

10. Pan Evaporation and Evapotranspiration in Iran. 1972. M.S. Thesis, USU, Khosvaui, A.R. (B)

11. The following three reports were prepared by Professor George H. Hargreaves and published by UNDP - World Meteorological Organization - Proyecto Hidrometeorologico Centroamericano.

    a. Necesidades y Requerimientos para Irrigacion, Arenal y Vecindades, Costa Rica. Published by PHCA (D)

    b. Necesidades y Requerimientos para Irrigacion, Comayagua y Vecindades, Honduras. Published by PHCA (D)

    c. Deficiencias de Agua en Centro America y Panama. In Press by PHCA, December 1972. (D)

12. Irrigation Requirements and Climatic Evaluation for Venezuela. 1971. Christiansen, J. E. and Hargreaves, G. H. (C)

13. Requerimientos para el Riego de la Caña de Azucar, Santa Cruz, Bolivia. 1971. Hargreaves, G. H. (D)

14. Irrigation Analysis for Selected Crops, Santa Cruz, Bolivia. 1972. (Also available in Spanish) Bolivian Utah State/USAID Study Team. (D)

Papers and Reports in Preparation

15. Requerimientos Hidricos de la Region Sud Oriental de la Republica Dominicana, Hargreaves, H. G. and Alfaro, J. F.; paper to be presented at the Symposium on Tropical Savana Soils, Santa Domingo, Dominican Republic, Jan. 22-26, 1973. (C)

16. Groundwater Extraction and the Water Balance. (A)

17. Irrigation Requirements for Grasses Including Turf. Hargreaves, G. H. (C)

18. Irrigation Requirements and Ground Water Development. Paper Prepared for presentation at the National Ground Water Symposium, Sao Carlos, Sao Paulo, Brazil, Nov. 27 - Dec. 1972. Hargreaves, G. H. (C)

Drainage

19. Irrigation and Drainage by Mole Systems. Progress Report, 1972. (A) Progress Report, 1971. (C), Unhanand, K.

20. Effects of the Shape and Speed on Soil Resistance of the Mole Plow. 1971. M.S. Thesis, USU, Kasap, R. (B)

21. Durability of Double Mole Drains. 1970. M.S. Thesis, USU, Sukwiwat, A. (B)

22. Mole Drainage Construction Optimum Moisture Content and Corresponding Power Requirement. 1970. M.S. Thesis, Polparsi, K. (B)

23. Irrigation Projects in Guatemala, Observations and Recommendations. 1972. Christiansen, J. E. and Olsen, E. C. III. (C)

Papers and Reports in Preparation

24. A Theory of the Combined Mole-Pipe Drainage System. Spring 1973. M.S. Thesis, Kadir, T. N. (B).

25. The Performance of a Combined Mole-Pipe Drainage System. Fall 1973. M.S. Thesis, Tuamsangiem, K. (B)

26. Performance of Combined Mole-Pipe Drains in Heavy Soils. Expect to complete, Fall 1973. Unhanand, K. (A)

Economics of Agricultural Water Management

27. Public Irrigation Projects, Wind-fall Gains and the Distribution of Income. Summer 1972. Proceedings, Western Agricultural Economic Association. LeBaron, A., Whitaker, M., and Wennergren, B. (C)

28. Economic Aspects of Irrigation from Ground Water. 1972. Presented at the Brazilian National Ground Water Symposium, University of Sao Paulo, Dec. 1972. Hargreaves, G. H. (C)

29. Relative Rates of Return to Controlled Irrigation Among Classes of Summer Paddy in the Guayas Basin in Ecuador. May 1972. Department of Agricultural Economics, USU, M.S. Thesis, Aitken, P. (B) & (C)

30. Impact on Rural Incomes and Imrpoved Water Management in Milagro County, Ecuador. May 1972. Department of Agricultural Economics, M.S. Thesis, USU, Lloyd, P. (B) & (C)

31. The Effect of Increased Water Supply on Net Returns to Dairy Farmers in Sonsonate, El Salvador. May 1972. USU, Whitaker, LeBaron, Wennergren, and Glenn. (A)

32. Evaluación Económica de Rotación Intensiva de Cultivos en Tierras con Riego. 1972. Prepared by the Centro Nacional de Tecnología Agropecuaria Dirección de Investigación Agropecuaria, El Salvador. (D)

On-Farm Systems Analysis

33. A Hybrid Computer Model of a Hydrologic System within the Atlantico 3 Area of Colombia, South America, Progress Report. June 1971. Riley, J. P. and Israelsen, E. K. (C)

34. Combined Surface Water - Ground Water Analysis of Hydrological Systems With the Aid of the Hybrid Computer. Published in Water Resources Bulletin Feb. 1972. Also published in Proceedings of International Symposium on Ground Water, Palermo, Italy, Dec. 1970. Morris, W. J., Morgan, N. W., Wang Bi-Huey and Riley, J. P. (D)

35. Hybrid Computer Simulation of Ground Water Regimes, Paper Presented at Annual Fall Meeting of American Geophysical Union, Dec. 1971. Wang, B. and Riley, J. P. (A)

Papers and Reports in Preparation

36. Computer Simulation for Change in Ground Water Elevation for Atlantico 3-Colombia. 1972. M.S. Thesis, Ely, M.S. (B) & (C)

37. A Computer Model for Simulation Ground Water Table Elevations. Riley, J. P. and Wang, B. (A)

38. Irrigation of Community Gardens in Panama. Christiansen, J. E. (A)

Project Progress Reports

Water Management Research in the Arid and Sub-humid Lands of Less Developed Countries.

39. Annual Progress Report June 1968 - Oct. 31, 1969 (A)

40. Second Annual Progress Report Nov. 1, 1969 - Oct. 31, 1970 (A)

41. Third Annual Progress Report Nov. 1, 1970 - Oct. 31, 1971 (A)

42. Fourth Annual Progress Report Nov. 1, 1971 - Oct. 31, 1972 (A)

Salinity Control

43. Estudios de Recuperación en los suelos de Textura Ligera y Mediana del Proyecto Atlantico 3 - Colombia. 1971. Watts, D. G. (C)

44. Report on Aquatic Weed Control and Water Quality Study in the Zapotitan Valley, El Salvador. 1971. Chase, R. E. (C)

Papers and Reports in Preparation

45. Effect of Agricultural Use on Water Quality for Downstream Irrigation Use. Christiansen, J. E. (A)

Water Application Techniques

46. A Pipe Bend Flow Meter for Measuring the Flow of Water From a Well. 1971. Griffin, R. E. (A)

47. Sub-Irrigation in the Zapotitan Valley, El Salvador. 1971. Griffin, R. E. (C)

48. Sprinkler System Distribution Evaluation Using the Superimposed Method. 1971. Griffin, R. E. (C)

49. Sprinkler Profile Analysis to Predict Field Performance. 1971. Published by American Society of Agricultural Engineers, St. Joseph, Michigan. Keller, J., Moynahan, M. D., and Ptacek, R. L. (D)

50. The Use of Sprinkler Profiles to Predict Field Performance. 1972. M. S. Thesis, Moynahan, M. D. (B)

51. Irrigation with Siphon Tubes. 1971. Centro Interamericano de Desarrollo Integral de Aguas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R. W., Guilarte, T., and Chavez, E. (D)

Papers and Reports in Preparation

52. Manejo Integral del aqua en la Produccion Agricola. 1973. Paper to be presented at the Symposium on Savannah Soils in the Tropics, Santo Domingo, Dominican Republic. Unhanand, K. and Alfaro, J. F. (A)

Water Inter-Actions With Other Variables

53. On-Farm Water Management Research in the Aconcagua Valley, Chile. Third Annual Report, 1971-72. Kidman, D.C., Stutler, R.K., James, D. W. (C)

54. Interim Report of Water - Soil - Crop Interaction Experiments in Chile. 1970-71. Kidman, D. C., and Stutler, R. K. (C)

55. Irrigated Corn Production Studies in the Zapotitan Valley, El Salvador. 1972. Griffin, R. E. (C)

56. Corn Studies in Los Llanos, Venezuela. 1971. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R. W., Martinez, E., Bustillos, A., Gonzales, A, and Guilarte, T. (D)

57. Irrigation-Fertility Studies with Caraota. 1971. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R. W., Martinez, E., Chavez, E., Bustillos, A., and Guilarte, T. (D)

58. Effectos de Diferentes Niveles de Riego y Fertilidad y Cultivo del Arroz. 1971. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R.W., and Bustillos, A. (D)

59. Investigations of Sugar Cane Growth in Las Majaguas, Venezuela. 1971. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R.W., Bustillos, A., and Guilarte, A. (D)

60. Summary of Cambur Study; The First Nine Months. 1970. Prepared in Spanish and English by Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R.W., Martinez, E., Gonzales, A., and Guilarte, T. (D)

61. Irrigation-Fertility Studies with Cambur. 1972. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R.W., Martinez, E., Gonzales, A., Guilarte, T., and Chavez, E. (D)

62. Research Activities in Water Use and Soils in Los Llanos, Venezuela. 1971. Centro Interamericano de Desarrollo Integral de Aquas y Tierra, Project 213 OAS, in cooperation with Government of Venezuela, University of Los Andes and Utah State University. Miller, R.W. (D)

Water Law

Papers and Reports in Preparation

63. Water Legislation in the Andean Pact Countries - Digest and Comparative Study. Daines, D. R. (C)

64. Irrigation Distribution Organizations in Ecuador. 1973. M.S. Thesis. Anderson, D. C. (B)

APPENDIX B

WATER LEGISLATION

IN THE ANDES PACT NATIONS

SUMMARY AND COMPARISON

TABLE OF CONTENTS

Bolivia	Chile	Colombia	Ecuador	Peru	Comparative		2nd and 3rd Title Numbers	
(1)	(2)	(3)	(4)	(5)	(6)			1st Title Number
Page Numbers								TITLES AND SUB TITLES
							( )-1-0	INTRODUCTION
							( )-1-1	References and Key to Abbreviations
							( )-1-2	Geography
							( )-1-3	Climate
							( )-1-4	Population
							( )-1-5	Irrigation
							( )-2-0	LEGISLATION
							( )-2-1	Legislation in Force
							( )-2-2	Process for Legislative Change
							( )-3-0	ORGANIZATION FOR WATER ADMINISTRATION
							( )-3-1	General
							( )-3-2	User Organizations
							( )-3-3	Registries
							( )-4-0	OWNERSHIP AND CONTROL
							( )-4-1	State Ownership
							( )-4-2	Private Ownership
							( )-4-3	Ownership and Control of Riverbeds, etc.
							( )-4-4	Control of Structures in Riverbeds, etc.
							( )-5-0	RIGHT TO USE WATER
							( )-5-1	Uses Without Formality

							( )-5-2	Procedure for Obtaining a Use Right
							( )-5-3	Procedural Protection of Rights
							( )-5-4	Rights Under Prior Laws
							( )-5-5	Limitations and Obligations of Users
							( )-5-6	Loss of Rights
							( )-6-0	OBLIGATORY WATER USE
							( )-7-0	PRIORITIES BETWEEN USE RIGHTS
							( )-7-1	Order of Priorities
							( )-7-2	How Priorities Operate
							( )-8-0	RIGHTS-OF-WAY RELATED TO WATER USE
							( )-8-1	Voluntary and Natural Rights-of-Way
							( )-8-2	Forcefully Imposed Rights-of-Way
							( )-8-3	Termination of Rights-of-Way
							( )-9-0	HARMFUL EFFECTS
							( )-9-1	Flood, Erosion Control and Conservation
							( )-9-2	Drainage
							( )-9-3	Contamination
							( )-9-4	Others
							( )-10-0	FINANCING WORKS AND ADMINISTRATION
							( )-11-0	LEGISLATION ON USES OTHER THAN IRRIGATION
							( )-11-1	Domestic
							( )-11-2	Motive Power, Industrial and Electrical Generation
							( )-11-3	Transportation
							( )-11-4	Medicinal and Thermal
							( )-11-5	Mining
							( )-11-6	Others
							( )-12-0	SUBTERRANEAN WATERS
							( )-13-0	PENALTIES AND SANCTIONS