Water Resources Research Institute
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RESEARCH PROJECT TECHNICAL COMPLETION REPORT

Project A-055-PR

A PRICING POLICY
FOR
GROUNDWATER MANAGEMENT IN PUERTO RICO

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ABSTRACT

The aim of this study is directed towards the internalization of external costs which fall upon established water users through the pumping of ground water from a common-pool by new water users. It is rationalized that these external costs to established users manifest themselves in additional pumping costs which are reflected primarily in incurrence of added energy costs. The determination of these costs which constitutes the basis of a price levied on new users and consequent compensation to established users was achieved through the development of a mathematical model. Through this model it is shown also that: (1) the greater the quantity of water extracted by new users, pumping (additional) costs were higher for established users; (2) the greater the distance between two wells, the additional pumping costs were correspondingly less for established users; and (3) when the distance is greater than the radius of influence (3,500 ft) no additional pumping costs were incurred.

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CHAPTER I

I. INTRODUCTION

The overall economic growth of Puerto Rico in the past has been very impressive and current indications appear to confirm that a similar trend may continue in the future but at a slower rate. However, this rate of growth directly dependent, among other factors, upon an adequate supply of water resources in order to stimulate practically all forms of productive activity. One local water resources scientist noted that "a failure of a seemingly inexhaustible source of water supply can close down industrial plants" that continue to constitute the core of the island's economic sustenance.[1] Because of this it is therefore imperative that adequate water supplies be assured if the economic future of Puerto Rico is not to be jeopardized.

Although the importance of water to Puerto Rico's economy is recognized, there is an incessant increase of use and users in the face of a fixed natural supply. In the residential sector where the demand is largely contingent upon population growth, the Puerto Rico Aqueduct and Sewer Authority (PRASA) still has about a half million people without direct water service. In the last decade annual water production by PRASA more than doubled, increasing from $62.0 billion gallons in 1967 to $114.5 billion gallons in 1977.[2] No doubt a similar tendency occurred in agriculture and industry.

Annual rainfall in Puerto Rico averages about 75 inches, but due to water losses primarily by run-off and evapo-transpiration, only 23 inches or 4.1 million acre-feet are considered as the "controllable supply".[3]

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[1] Guilbe, Ausberto, Quantitative Analysis of Water Use Patterns in Púerto Rico, Technical Completion Report A-003-PR, Office of Water Research and Technology, U.S. Department of the Interior, Washington, D.C., 1969.

[2] Puerto Rico Aqueduct and Sewer Authority, Banco de Información:Estadísticas Generales, San Juan, Puerto Rico, 1978.

[3] Avilés Cordero, Isidoro, The Management and Control of Water in Puerto Rico, Technical Completion Report A-010-PR, Office of Water Research and Technology, U.S. Department of the Interior, Washington, D.C., 1969.

Since it is estimated that only one-third of the annual rainfall is the controllable supply, it is therefore evident that an additional 2.7 million acre-feet are available for both current and future uses.[4] In the light of unrestrained increases in residential, agricultural, and industrial sectors this additional supply can rapidly diminish in the near future if appropriate measures are not taken to control demand. Demand can be effectively controlled by a proper pricing policy but in Puerto Rico it was never so since the price mechanism was designed to stimulate it.

Apart from an intricate demand situation, a more imminent problem which confronts Puerto Rico is that the natural water supply is not equally distributed in time and space, and not all the centers of demand are located within regions of great natural availability. The contrast is more significant between the north and south coasts, where the average flow on the former is 1720 mgd and the latter 590 mgd. On the south coast most of the limited surface and ground water has already been developed and yet this is where some of the largest water users are located. In a situation like this where demand appears to exceed, or is expected to exceed natural supply, competition arises among uses and water users which in turn generate conflicts if water rights are not adequately defined.

The solution of potential conflicts for a product in a market economy can be provided, if not wholly at least partially, by the price system. The general function of the price system is to assert checks and balances on production and consumption. In this role prices have two functions: (1) to discourage excessive demand of a product; and (2) to induce the desired supply of that product. In Puerto Rico the price charged for water resources needs to be restructured on the basis of the market forces of water supply and demand in order to achieve a rational allocation of the resource based

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[4] Ibid.

on economic criteria. In some areas, in particular with respect to ground water, the total lack of a pricing policy has resulted in an unlimited or even abusive extraction of water such that permanent depletion of aquifers appears imminent.

1.1 The Problem

The effect of irrational withdrawals of ground water and the maldistribution of the same is being felt throughout Puerto Rico, particularly in areas where the quantity demanded is approaching or already exceeds the quantity supplied. The water table in some areas has been considerably lowered below the safe-yield level and salt water intrusion into aquifers is already occuring. The realization of this intrusion will become more widespread as surface water becomes more contaminated and one has to resort to more groundwater extraction.

The costs arising from excessive withdrawals of groundwater result from a special feature associated with the resource. This feature relates to the interdependence of withdrawals which is generally reffered to as the "common pool problem". When water is pumped from ground sources, the pumping usually takes place in common among many individual pumpers. In the course of pumping "negative externalities" or "spill-over costs" arise where all of the costs of extra pumping do not fall upon the individual pumper but are borne instead by other pumpers using the same water course.

The spill-over costs created by the exploitation of a common supply of water are of two major types. The first and most serious is that each pumper at the common source of supply has no incentive to maximize the present value of total future extractions because he has no property rights which are valid in the future. Each producer has the incentive to pump as long as the current marginal returns exceed his current marginal costs with the result that possible future values of the remaining supply are ignored.

On the southern coast of Puerto Rico both agricultural and industrial enterprises are pumping a large quantity of water which is greater than the annual recharge of water aquifers. This over-utilization of water resources imposes an external cost to individuals and society and should be borne by the respective pumpers who are responsible for its generation.

The second major type of spill-over cost results when one pumper lowers the level of the water pool and thus part of the cost of extra pumping lift is then borne by all of the common pumpers. This situation is extremely common on the South Coast of Puerto Rico between industry and agriculture and for this reason this study takes this latter type of externality as its primary objective. The additional costs created by pumping must be internalized and the affected production entity should be compensated by the originator of such costs.

1.2 Objectives of Study

To facilitate an analysis of the problem previously described, the objectives of this study are as follows:

(1) To analyze and evaluate the actual water situation on the South Coast of Puerto Rico.

(2) To review economic theory pertinent to the allocation of a resource characterized by communality in use,

(3) To estimate, through a mathematical model, the identifiable external costs associated with commonality of water use, and

(4) To determinate the impact of the radius of influence among users from the common water pool.

1.3 Limitations of Study

As with most mathematical models, there are always certain assumptions which may or may not concord with reality. The model herein developed is no exception and assumptions are outlined on page 25.

This study does not pretend to estimate all external costs caused by commonality in groundwater use. Up to this point in time, true or accurate estimates of these costs have eluded economists because of the difficulties encountered in their identification and method of empirical estimation. As a consequence the results of this study do not provide a solution to the externality problem but instead represent a modest step in this direction.

1.4 Method of Study

The information available on the subject of this study were rather limited since apparently no public or private water agency undertook a formal and systematic approach towards the determination of a pricing policy for underground water in Puerto Rico.

The methodology utilized in the study consists primarily of a theoretical mathematical model designed to determine the level of compensation or the price new users are expected to pay current users for the unnecessary additional costs created in the extraction of water.

To empirically test the model, the relevant data were collected for and from a specific site - the Barinas Valley in the municipality of Yauco on the southern coast of Puerto Rico. In this valley, the subterranean water levels have reached a critical zone and salt-water intrusion is imminent. With computer assistance, the data and the model were analyzed and the results are discussed herein.

CHAPTER 2

REVIEW OF ECONOMIC THEORY

I. THE CONCEPT OF EXTERNALITY

The concept of externality is frequently defined as "the costs and benefits imposed upon or received by others as a consequence of private actions not normally taken into consideration in private decision".[5]

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[5] Hirshleifer, Jack, James C. De Haven and Jerome W. Milliman, Water Supply: Economics, Technology, and Policy (Chicago: University of Chicago Press, 1966).

These actions can cause divergencies between private costs (benefits) and social costs (benefits). Frequently the private costs differ from social costs because of the lack of definition and the enforcement of property rights of the resource that is being utilized.[6] A classic example is the decrease of fresh underground water supplies where pumping is done in common.

The private costs differ from social costs because persons who take decisions do not consider the external costs which fall on society. The effects of these external costs can be illustrated on Fig. 1. PSS, the Private Supply Schedule for product x is the horizontal summation of only internal or private costs of production, i.e. marginal private costs. Assuming the existence of a negative externality which could be caused by overpumping of groundwater, SSS, the Social Supply Schedule curve lies above PSS reflecting the difference between the marginal private and social costs for all firms in this industry. The vertical distance between these two schedules is the aggregate of the external costs imposed on society for any given level of output by the industry.

On the basis of Fig. 1, and assuming rational behavior, the industry should be producing the quantity OK in order to use resources efficiently or optimally from society's standpoint. However, this is not so since the quantity OM is produced and OM is greater than OK. The added production KM is due to the fact that individual firms do not include the external costs in their profit-maximization calculus, i.e. they do not provide for their internalization. From a social view, KM represents a misallocation of resources or relative inefficiency in the use of economic resources which should be diverted to producing another product where maximum

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[6] Miller, Roger Leroy, "Intermediate Microeconomics: Theory, Issues, and Applications (New York: McGraw Hill Book Company, 1978).

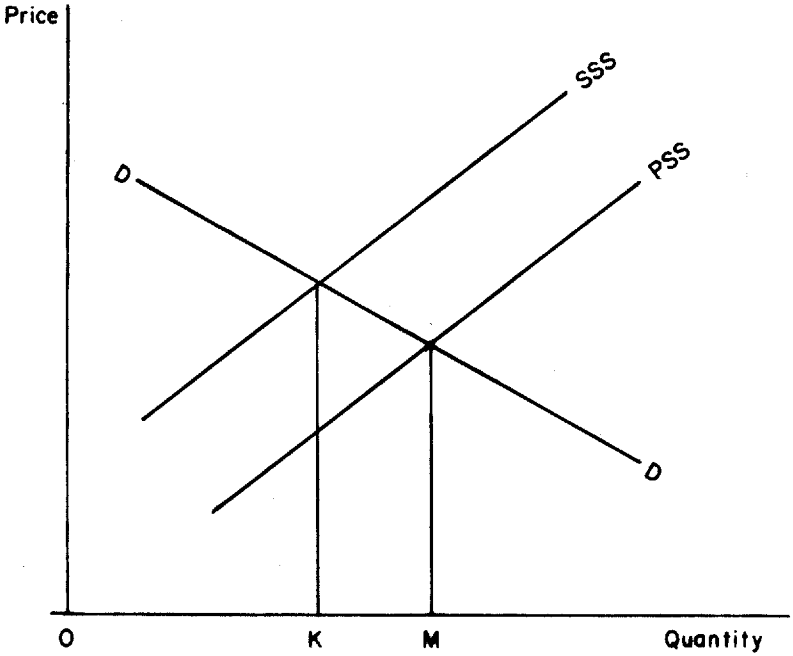

Figure 1. The Effect of External Costs on the Allocation of Water.

efficiency of use can be achieved. Therefore when the market fails to internalize external costs, society is forced to bear the cost resulting from the diminished production and comsupmtion of goods and services. Because of this there should be economic measures which can force decision makers responsible for all costs associated with their actions. These measures should seek to equalize social costs with private costs and thereby avoid unnecessary adverse effects on society. However, this is not a simple task since the major problem lies in the true estimation of these social costs.

One of the primary causes for the existence of divergencies between social costs and private costs is that property rights are not well-defined or when well-defined there is a lack of enforcement. Under either situation, a user has no incentive to conserve and efficiently use a particular resource. This is quite common in water resources where all users take water from the common pool. In the case of groundwater specifically the lack of defined water rights fosters excessive pumping and consequent reduction of the water level by some users who are not required to compensate others using water from the same water basin or water pool.

When property rights exist, individuals have the right to legal action for any damage done to property,whether public or private. If property rights are well defined the use of resources will involve the transference of rights from the owners to potential users as in the private market system. Actually what occurs in the process of exchange in the market is the payment of a price which in turn confirms property rights on the purchaser of the resource. From a legal perspective the private market system may be viewed as a social mechanism for the voluntary transfer of property rights through contracts than are legally enforceable by appeal to the coercive power of the state. Therefore externalities may be explained as the consequence either of an incomplete set of property rights or by the failure of the state to enforce public or private property rights.

The definition of property rights is a complicated subject and becomes extremely difficult when resources are commonly-owned. Such resources are the property of everyone but no one owns them. This is true in the case of extracting underground water and is generally referred to as the "common pool problem" in water resources literature.

The common pool problem occurs when a number of overlying property owners are engaged in competitive pumping of water from a common underlying aquifer since rights in percolating groundwater can normally be obtained only by actual "capture" of the water. Because of this pumpers are inclined to withdraw water at a rate greater than would otherwise be rational for fear that the withdrawals of others will lower water levels in the wells. Each pumper considers in his decision, only the effect of his pumping and does not consider the fact that his pumping will adversely affect all those interested in the pool.

It is important to note that the common pool problem is a manifestation of the "fugitive" nature of water resources. The span of property rights in such resources fails to include all the significant consequences of the private exploitation decisions. Ordinarily the inducements are such as to encourage excessive exploitation since a decision to conserve for future uses does not provide a property right in the preserved resource still subjected to the law of capture.

There are three possible solutions or methods for assuring that decisions made will meet the criteria of allocative efficiency to solve the common pool problem. These are (1) centralized decision making, (2) assignment of pro-rata production or quotas, and (3) the imposition of "use" taxes.

Centralized decision-making can be pursued in many ways with the most prominent being either sole ownership of the pool (public or private) or detailed public regulation. Unitization refers to the proposal where individual owners surrender competitive withdrawal rights in exchange for a fractional share in the whole pool, the latter to be managed by a committee or agent. This may develop because the value of the pool under centralized management is greater than the sum of the private values under competitive withdrawal rights.

The application of centralized decision-making is not without problems. First a central issue will be to determine the size and extent of the pool and its connection with other pools. The water pool may not be isolated and as a consequence the problems of a specific pool may be difficult to define. Variable local conditions may change with different but interconnected pools. The only alternative to such a situation would be centralized administration of all interconnected pools but this can create both administrative and political difficulties especially in pools that are within different political or geographic boundaries. Even if the pool is localized another problem arises when water is extracted from the same pool for multiple users. This is true when water is being diverted for use simultaneously in irrigation, industrial or domestic purposes. The returns from each use per unit of water is different even if these returns can be measured or estimated. Because of this, decision-making becomes a complex task.

Sole ownership has rarely been the solution arrived at for common pool problems arising in the exploitation of water resources. The solution by means of pro-rata assignment of quotas is more popular particularly when the assigned quantity of water is based on historical use. The advantages of such an assignment includes its simplicity and directness. A point of great practical importance is that the goal of the assignment is not a difficult and subtle matter of optimal use but an "equitable" apportment of rights among claimants. Another advantage is that in a certain sense the assignment of quotas gets really to the heart of the problem - the common nature of the resource - by replacing commonality of rights with specificity of shares. The assignment of quotas does pose some problems. First there is the matter of "equitable" apportionment. Secondly, there the question of efficiency. A single user for example may concentrate all his withdrawals on a few wells near the more productive lands whereas an equitable apportionment might give a distribution of quotas whose exploitation through a great many well leads to some social waste. The third and most serious difficulty rests upon the question of how to achieve rationality in the use of the resource over time.

The third method of implementing the use-tax is probably the best. The economy theory behind this method is based on the following consideration. Each pumper in deciding how much water to withdraw, compares the marginal cost of pumping with the marginal value in use to him of the water. This will usually be the value of the marginal product, the water being normally used as an intermediate good in the production of goods and services for the market. But his withdrawals will tend to lower the water levels for everyone using the common pool, a consideration which he will ignore or at least not consider fully because the impact on himself will be partial and may be negligible. In this case, the use-tax solution would require a payment which would be added to the cost of pumping so that ideally the individual would consider the marginal social cost in his decision on how much to pump rather than merely the marginal private cost. The payment of course would present the loss of productivity on lands owned by others. Figure 2 illustrates this solution. The curve labeled VMP represents the

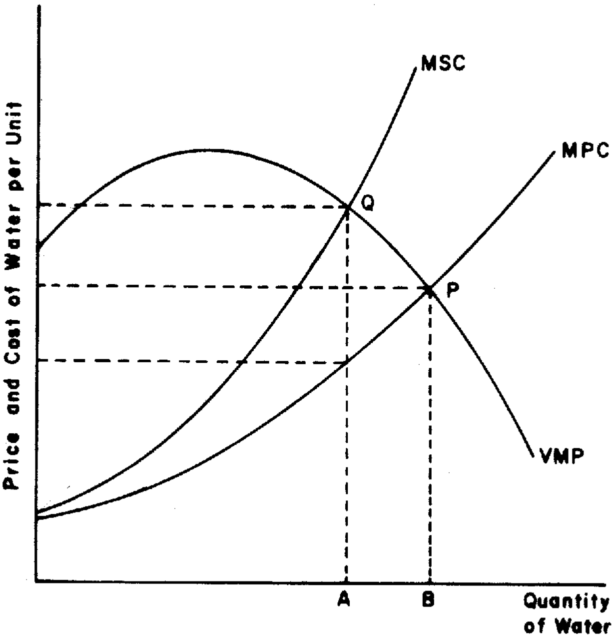

Figure 2. The Use—Tax in Water Allocation.

value of the marginal product of water pumped for a typical individual pumper. After a certain point the curve turns downward because of diminishing returns as more and more water is applied to the productive process in question. The curve MPC represents the marginal private cost of getting water, that is, the cost of pumping water plus cost due to lowering of the water level under the individual's own land. The curve MSC or marginal social cost differs from MPC, in that it includes the cost due to lowering of the water level under others' lands. The ideal use tax would be a sliding scale equalling for any quantity of water withdrawn the vertical differences between the MPC and MSC curves. Given the tax pattern each individual would then be effectively operating along the MSC curve and he would have to pay the cost of pumping and also the tax. In the absence of such a tax, the individual would tend to operate at point P, where output is OB (since to the left of P he can increase output and incur an MPC which is less than VMP gained, while to the right of P the opposite occurs). However, from the social point of view all the output between OA and OB involves a loss because MSC is greater than VMP in that range. With the tax a rational individual will pump only to the point Q (output OA) where MSC equals MVP. In theory this tax system appears very plausible but in reality it may be difficult since an ideal tax would vary for each individual in such a way as to reflect all the social costs that are relevant. This can create serious administrative and operational problems even if all social costs can be actually measured. The latter is not an easy task and for this reason the tax may have to be uniform but subject to change when variations in VMP and/or MPC occur. To avoid all this complexity, the quota system is generally preferred with OA (Fig. 2) representing the amount allowed to a specific pumper. The strongest arguments in favor of quotas are their simplicity and comprehensibility of the solution and the fact that quotas come closet to remedying the logical essence of the common-pool difficulty - the non-specificity of property rights.

CHAPTER 3

3.1 The Water Situation on the South Coast

The Supply of Water

The South oast of Puerto Rico occupies an area of approximately 734 square miles and consists of the following municipalities: Guánica, Yauco, Guayanilla, Peñuelas, Ponce, Villalba, Juana Díaz, Santa Isabel, Coamo, Salinas, Guayama, Arroyo, Patillas and Maunabo (Fig. 3). The population of the area is estimated at about 500,000 currently and is primarily concentrated in urban areas along the flat plains of the coast. The average annual rainfall ranges between 30-40 inches and occurs predominantly in the months of September, October and November. Because of this relatively low level of rainfall (Puerto Rico averages about 75 inches unnually) it is regarded as an extremely dry area on the island. Apparently the degree of dryness is becoming increasingly more severe since consistent water shortages and even droughts have become common occurences in the area particularly during the summer months.

The usable water supply on the south coast is estimated at 343.0 million gallons per day with a little more than half (50.7 percent) being derived from groundwater sources (Table 1). The largest aquifers supplying groundwater consist of interlocking bands of sand and gravel and are located in the municipalities of Tallaboa, Ponce and Patillas. Traditionally the water pumped by deep-wells which number about 200 currently, is used primarily for irrigation but with the advent of heavy industries in the area in recent years a large amount of groundwater is now used to meet industrial needs. also. In addition, the Puerto Rico Aqueduct and Sewer Authority maintains a series of wells on the coast in order to provide an ample supply of potable water to residents of the area.

Figure 3

Municipalities of the South Coast of Puerto Rico

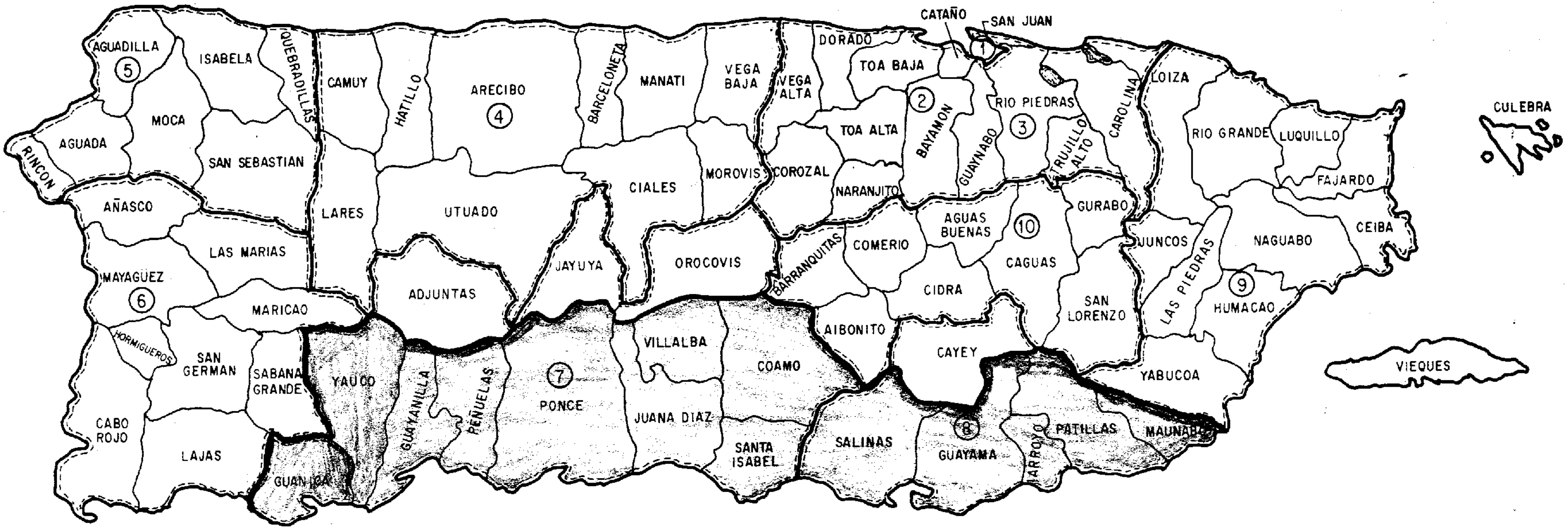

TABLE 1

Supply of Fresh Water on South Coast, Puerto Rico 1975

Water Source	Quantity (MGD)	Percent
A. Ground Water	174.0	50.7
B. Surface Water	169.0	49.3
1. Rivers and Canal	33.0	9.6
2. Lakes and Reservoirs	131.0	38.2
3. Desalinated Water	5.0	1.5
Total	343.0	100.0

Source: U.S. Corps of Engineers, Review Report for Ponce Regional Water Resources Management Study, Appendix B, San Juan, Puerto Rico, 1975.

On Table 1, it is shown that surface water accounts for a daily supply of about 169.0 million gallons or 49.3 percent of all fresh water on the south coast. Of this amount the greater part, 131.0 million gallons per day or about 80.0 percent of the total, is derived from freshwater lakes and reservoirs, while the remainder is obtained from other minor sources such as rivers and canals.

On the south coast there are 12 lakes or reservoirs but six of these fall outside the political boundaries of the area. Some of these reservoirs are interconnected by means of water tunnels forming a water system while some operate independently. Two such systems which exist on the coast are the Yauco system consisting of Yahueca, Guayo Prieto, Lucchetti and Loco reservoirs; and the Toro Negro system which includes the reservoirs of Matrullas, Guineos and Guayabal. The independent reservoirs are Garzas, Carite and Patillas.

The greater part of water supplied by all reservoirs is still being used for irrigation and is distributed exclusively by the South Coast Irrigation District which consists of the following three water distributions systems: (1) The Patillas System which incorporates 45 miles of lateral irrigation canals and stretches from the Patillas reservoir to the Salinas River; (2) The Juana Díaz System,some forty-three miles in length and supplying irrigation water to all agricultural lands between the Jacaguas River and the Salinas River; and (3) The Carite System which is similar in length and purpose as the Juana Díaz System.

There are about twenty-five rivers and canals on the south coast that originate in the Cordillera Central and discharge into the Caribbean Sea. Compared with those of the north coast, the south coast rivers are shorter and possess greater slopes which hinder the proper infiltration of water on the land and consequently generate a rapid discharge of water to the sea. Because of this, most of these rivers have very low flow level and some are even dry at certain periods of the year.

The sea as a water source on the south coast has been utilized primarily by heavy industries particularly the sugar factories, petroleum refineries and pharmaceutical plants located in the municipalities of Guayanilla, Peñuelas and Salinas. These industries use around 2,085 million gallons of sea water daily for cooling. In addition another 5.0 million gallons per day of desalted water is used primarily by the Commonwealth Oil Refining Company (CORCO) for industrial production.

3.2 The Demand for Water

The demand for fresh water on the south coast stems from use within agriculture, industry, and the municipalities which includes residential, commercial and public uses as well. Among the different uses, agriculture accounts for 78.1 percent of total water demand and for this reason the lack of groundwater can create adverse circumstances in agricultural production. These circumstances can be aggravated particularly when droughts, as mentioned previously, occur at certain times of the year.

TABLE 2.

Demand for Water on the South Coast, Puerto Rico 1975

Water Use	Quantity (MGD)	Percent
Agricultural (Irrigation)	230.2	78.1
Industry (Processing)	39.4	13.4
Municipal (Residential, Commercial and Public)	25.0	8.5
Total	294.6	100.0

Source: Ibid.

In 1975 the 230.2 million gallons per day of water (Table 2) used in agriculture were dedicated to the irrigation of some 48,000 acres of land of which 93.0 percent was utilized for the cultivation of sugar cane. This use pattern is likely to change considerably in the near future because of the current strategy of agricultural development being undertaken by the government whereby the cultivation of green vegetables is being emphazized at the expense of sugar cane. The materialization of this strategy will require larger quantities of water and a change in the time distribution of water use. A more stable and consistent demand is expected since green vegetables will be grown year round.

Industrial water demand on the south coast is small compared to agriculture and this is due to the fact that industrial activity is relatively limited. Most industries established in the area are heavy in nature and have a low level of consumptive use that ranges between 4.0-6.0 percent. To a large extent, these industries use proportionally more groundwater since it is relatively more economical than desalinated water or supplies obtained from PRASA. The cost incurred for groundwater relates only to well-construction initially and thereafter the maintenance of pumps and the cost of energy.

Municipal demand arises from use in residences, commercial enterprises and the municipal government. This demand is met by supplies provided by the Puerto Rico Aqueduct and Sewer Authority which derives about sixty percent of its total supply from groundwater sources. The rest obviously is supplied by surface water.

An unusual situation with respect to industrial demand for groundwater is that most of the industries are characterized by a high level of water intake in the municipalities where the availability of groundwater is relatively low. The petroleum and chemical plants which form the core of the industrial complex in the area are located primarily in the municipalities of Guayanilla and Peñuelas where the groundwater supplies account for about 10.0 percent of the total amount available on the entire south coast. Already a deficit of 2.0 million gallons per day exist in Guayanilla and as a consequence saltwater intrusion is imminent. Deficits of 15.0 mgd in Ponce and 1.0 mgd in Guayama exist while a critical stage has been reached in the other municipalities where a small surplus still remains ranging from 1.0 mgd in Salinas to a maximum of 5.0 mgd in Peñuelas. Based on the trend of current demand, a reasonable projection may well indicate a consistent decrease of this surplus resulting ultimately in its eradication if efforts are not made to restrict demand or augment present supplies. These efforts should be selected and directed towards the possibility of increasing available water supplies and at the same time promoting greater economic efficiency in its use.

One method of increasing available supplies in the region is to reduce water losses which account for some 27.8 million gallons per day. Although total elimination of water losses is practically impossible it should be recognized that in a water-shortage area as the south coast there should be a greater drive towards achievement of efficiency through minimization of water loss. One may postulate that the 9.0 percent of total water supply that is lost is relatively low, but this postulation has no meaning if it is not put into the context of current water demand and the adverse water situation which exists on the south coast. On the basis of this situation it should be concluded that the level of water loss in relatively high and steps should be taken towards its immediate remedy to avoid jeopardizing the future economic and social development of the south coast.

3.3 The Study Area

The selected area of study is known as the Barinas Valley located in the municipality of Yauco and consists of approximately 2,437 acres of very flat and fertile land. This valley was selected because it serves as an appropriate example on the south coast where excessive pumping by newly established users and/or larger industrial water consumers are adversely affecting water use by the established agricultural users. Because of this, farmers are forced to bear additional costs external in nature, that are not associated with their pumping of underground water. These costs therefore become a typical externality problem, negative in character, for which compensation of any form is not provided to the established user.

The present water situation in the Barinas Valley is serious because of discrepancies in water supply and demand. The total water supply is derived from groundwater sources that are now threatened by salt-water intrusion because of an excessive demand and consequent over-extraction. Should this situation continue all water consumers and society in general will most likely have to bear the costs of permanent destruction of groundwater sources in the valley.

The larger water users in the valley, both agricultural and industrial, obtain their supplies from the Barinas aquifer which has played an invaluable role in the production of the principal crop in the area - sugar cane. The eight agricultural users located in the valley extract about 11,500 gallons per minute while the two industrial users which maintain and operate wells - Pittsburg Plate and Glass (P.P.G.)* and Union Carbide Caribe Industries (U.C.C.I.) - pump approximately 3,075 gallons per minute throughout the entire year.

The wells in the Barinas Valley are located around the Yauco River and were perforated close to the land surface. The water flows of wells for agricultural use are generally greater than that of industry with differences in profundity due to geographical location. Normally those wells closer to the sea coast are shallower than those inland where the terrain is generally higher. These wells extract a considerable amount of water in an area within the municipality of Yauco which is considered to have the most formidable water suuply problem in Puerto Rico. The wells, twenty-nine in (Fig. 4) number ranges in profundity from a low of 80 feet to a high of 200 feet and have capacities ranging from 100-1000 gallons per minute. All wells except two small ones, are owned and operated by five major producing enterprises in the Barinas Valley (Table 3).

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* P.P.G. ceased operations in 1979.

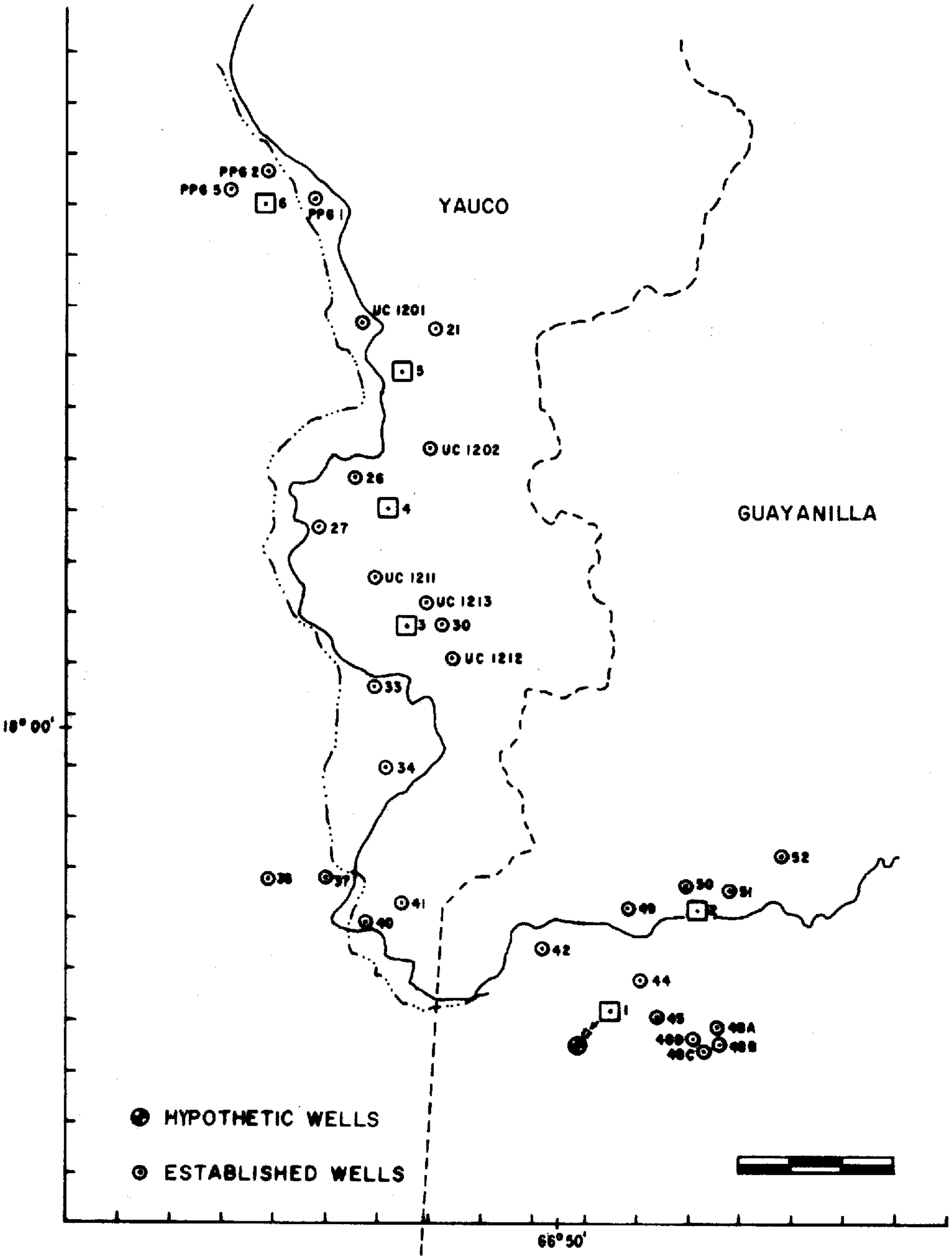


Fig. 4. Deep Wells in Berinas Valley, Yauco, 1978

Table 3

ells of the Barinas Valley, Yauco, Puerto Rico 1978*

1 ES -Axis	WATER LEVEL (feet)	DEPTH (feet)	CAPACITY (gpm)	PUMPING COST $/cubic ft/lift ft.	CAPACITY Cubic feet/day
20667	65'	170'	425	0.00000720	81818
20333	57.5'	115'	300	0.00000720	57754
20133	70'	132'	375	0.00000720	72192
17667	34.5'	108'	450	0.00000720	86631
15233	73'	200'	300	0.00000720	57754
12700	62'	121'	625	0.00000720	120320
12167	62'	125'	300	0.00000720	57754
11100	62'	131'	300	0.00000720	57754
6800	35'	150'	1000	0.00000720	192513
17533	30'	80'	450	0.00000720	86631
13667	35'	150'	100	0.00000720	19251
6333	35'	125'	800	0.00000720	154010
4833	35'	147'	500	0.00000720	96257
4067	35'	100'	500	0.00000720	96257
3900	35'	100'	100	0.00000720	19251
3567	35'	100'	100	0.00000720	19251
3433	35'	100'	300	0.00000720	57754
3637	35'	100'	300	0.00000720	57754
6233	35'	100'	1000	0.00000720	192513
6667	35'	100'	200	0.00000720	38503
6600	35'	100'	860	0.00000720	165541
7300	35'	140'	850	0.00000720	163636
9000	35'	115'	800	0.00000720	154010
6833	35'	120'	700	0.00000720	134759
5933	35'	115'	200	0.00000720	38503
5433	35'	150'	800	0.00000720	154010
0533	30'	110'	300	0.00000720	57754
4633	35	100'	800	0.00000720	154010
1733	30'	150'	1000	0.00000720	192513

am.

Natural Resources and the Puerto Rico Aqueduct and Sewer Authority

CHAPTER 4

4.1 The Model

One of the objectives of this study is to develop a mathematical model which will serve as a guide in the determination of external costs created by the use of groundwater with the aim of developing an appropriate charge for the same. The model develops some mathematical functions which can be utilized in the calculation of the additional energy cost (the primary external cost) which established water users incur when new users extract water from the same source. The creation of this cost to established users should be compensated for and should be included in the profit calculation (internalized) as a private cost of production of the new water users.

The assumptions of the model are:

(1) A fixed number of established users exist in the area of study.

(2) A user wishing to establish in the area requires a capacity of Q (acre feet/year) during a period of N years. He will be drilling M wells.

(3) A structure of water-rights exist which provides an annual capacity or quota for each user.

(4) The aquifer can supply the water requirements of the new user for the period of N years.

(5) The new user increases the pumping cost of the established users.

(6) Withdrawals produce drawdowns that are small relative to the saturated thickness of the aquifer.

(7) All wells are fully penetrating, hence a linear relation exist between pumping and drawdown.

The variables are defined as follows:

(1) T = number of established users in the area

(2) MM(T) = number of wells of Tth each user

(3) QQ(K,T)= Quota for Kth. well of Tth. user (acre-ft/yr)

(4) H(K,T) = Initial lift (feet) of Kth. well of Tth. user plus whatever drawdown due to pumping during a previous period.

(5) S(K,T,N)= Drawdown of Kth. well of Tth user at the end of Nth. time period.

(6) D(K,T,KK,TT,N)= Drawdown at Kth. well of the TTth. user due to pumping from the KKth. well of the TTth. user for year N.

(7) C(K,T) = energy cost ($/acre-ft/ft. of lift) for well K of Tth. user.

(8) CC(T,N) = cost of energy for Tth. user at the end of year N

(9) T + 1 = new user

(10) M = number of wells which the new user T + 1 requires, and

(11) Q(j*,N) = withdrawal from j* new well in year N (acre-ft/yr)

The purpose of this model is to estimate the additional cost created to established users in a given area by the establishment of wells by new water users. The presence of a new user lowers the groundwater level and therefore forces the established users to bore deeper to obtain their regular water supply. Obviously, the additional boring will generate additional costs to the established user particularly with respect to energy costs if it is assumed that current physical facilities are adequate for the extra pumping.

The average annual energy cost for Tth. user for N years is given by equation (1):

$$\sum_{i=1}^{N} \sum_{K=1}^{MM(i)} C(K,i)QQ(K,i) \left[S(K,i,N) \quad H(K,i)\right] \qquad (1)$$

When the new user is established the drawdown in well K of the Tth. user at the end of year N will be due to three factors:

a. The pumping of wells belonging to the same user T

b. The pumping of wells of the other users T-1

c. The pumping of M wells of the new user T+1

The drop in the water table results from excessive pumping of water from all wells in the area. The sum effect of the three factors mentioned above is given by equation (2).

$$S(K,i,N) = \sum_{K*=1}^{MM(i)} D(K,i,K*,i,N) + \sum_{\substack{i*=1 \\ i* \neq i}}^{T} \sum_{K*=1}^{MM(i*)} D(K,i,K*,i*,N) + \sum_{K^*=1}^{M} D(K,i,K^*,T+1,N) \qquad (2)$$

The extraction of underground water is the best example of the common pool problem where all users are extracting water from the same aquifer as in the case of the Barinas Valley. The private decisions of each user to pump water affect adversely the production and consumption of all residents in the area and the entire region as well. The arrival of a new user aggravates the problem further to established users in the generation of additional costs for water production. These costs are assumed to be for energy. The equation to estimate energy cost for the Tth. user at the end of year N due to the new user is:

$$CC(i,N)= \sum_{K=1}^{MM(i)} \sum_{j^*=1}^{M} C(K,i)\ QQ(K,i)\ D(K,i,j^*,T+1,N) \qquad (3)$$

The added energy cost CC(N) for users in period N is given by equation (4).

$$CC(N)= \sum_{i=1}^{T} CC(i,N) \qquad (4)$$

The drawdown in well K at the end of the year N due to M new wells is:

$$S(K,i,N)= \sum_{j^*=1}^{M} D(K,i,j^*,T+1,N) \qquad (5)$$

and finally equation (6)

$$CC(i,N)= \sum_{K=1}^{MM(i)} C(K,i)\ QQ(K,i)S(K,i,N) \qquad (6)$$

which expresses the energy cost for the Tth. user at the end of year N.

4.2 Description of the Program

Technically, the purpose of this program is to calculate the added energy costs which established users will incur with the establishement of a new water user. The first part of the program includes information related to well characteristics and capacity, the number of users, the "planning horizon", the coefficient of permeability, the water table and the impervious zone depth in the study area. Data for new users are hypothetical in nature and were selected based on similar characteristics of a corresponding established water well.

The next step in the program was to calculate the reduction in the water level, if any, in existing wells due to the establishment of new water users. First the distance between an established well and a new well was calculated and this was compared with the distance of no interference which in this case was assumed to be 3500 feet. Then the formula to calculate the capacity of wells in non-confined aquifers was used:

$$Q = \frac{\pi K(h_o^2 - h_1^2}{\log_e(r_o/r_w)}$$

and rearranging in the form:

$$(h_o^2-h_w^2) = \frac{Q}{\pi K} \log_e\frac{r_o}{r_w} \text{ where}$$

Q = Flow of new well

π = 3.1415

K = Coefficient of permeability

r_o = Distance of no interference between wells

h_o = Elevation of water to distance r_o

r_w = Distance of established well (less than r_o)

h_w = Elevation of water of established well

This was used to obtain by how much the water level of the established wells decreases due to the pumping capacity Q of the new well. The cost associated with this decrease is determined by using equation (6) of the model. The cost for energy is given in dollars per year for each user. This value is accumulative for all years included in the program.

A flow diagram outlining the details of the program is shown in Appendix 1. A complete description of the program can be found in the Appendix 2.

CHAPTER 5

Results and Conclusions

As mentioned previously, this study is aimed at estimating the additional costs generated to established water users as a result of the pumping activities of newly established water users in a given area. It is rationalized that the additional costs to the established users will manifest themselves primarily in the cost of energy since their wells with their corresponding depth and pumping capacity have already been constructed and as a consequence the fixed costs of pumping have been realized. Cost changes will result from variable pumping costs which would vary directly by an amount equivalent to additional energy costs incurred by established pumpers in the area. The cost of energy and consequently pumping was assumed to be $.0000072 per cubic foot per foot of lift.

To obtain the added energy costs the computer program was run in the first instance with data related to established users. In a second step, hypothetical data relevant to new users were incorporated in the model in order to generate the expected incremental energy costs created by their extraction of water (Table 4).

Table 4

Hypothetical Data for New Users (Wells) in the Barinas Valleys
Yauco, P.R.

New User	Geographical Location from an arbitrary origin X Coordinate	Y Coordinate	Water Level	Pumping Cost ft^3/ per ft/ of lift	Flood ft^3/d
User 1	10500 (ft)	4200 (ft)	35 (ft)	0.00000720	19251
User 2	12200 (ft)	6200 (ft)	35 (ft)	0.00000720	165561
User 3	6500 (ft)	11800 (ft)	62 (ft)	0.00000720	86631
User 4	6200 (ft)	14200 (ft)	35 (ft)	0.00000720	154010
User 5	6500 (ft)	16800 (ft)	62 (ft)	0.00000720	86631
User 6	3800 (ft)	20000 (ft)	65 (ft)	0.00000720	72192

Table 5

Accumulative Energy Cost for Established Users Before Establishment of New Users ($/Yr)

	ESTABLISHED USERS*									
Year	1	2	3	4	5	6	7	8	9	10
1	4452	7994	6273	22301	3238	2833	809	3238	1214	7285
2	8904	15987	12547	44602	6476	5666	1619	6476	2428	14571
3	13356	23981	18820	66903	9714	8500	2428	9714	3643	21856
4	17809	31974	25094	89205	12952	11333	3238	12952	4857	29141
5	22261	39968	31367	111506	16190	14166	4047	16190	6071	36426
6	26713	47962	37641	133807	19427	16999	4857	19427	7285	43712
7	31165	55955	43914	156108	22665	19832	5666	22665	8500	50997
8	35617	63949	50188	178409	25903	22665	6476	25903	9714	58282
9	40069	71942	56461	200710	29141	25499	7285	29141	10928	65568
10	44521	79936	62735	223011	22379	28332	8095	32379	12142	72853
11	48973	87930	69008	245313	35617	31165	8904	35617	13356	80138
12	53426	95923	75281	267614	38855	33998	7914	38855	14571	87424
13	57878	103917	81555	289915	42093	36831	10523	42093	15785	94709
14	62330	11910	87828	312216	45331	39664	11333	45331	16999	101994
15	66782	119904	94102	334517	48569	42498	12142	48569	18213	109279

* Users

1. Pittsburg Plate Glass
2. Union Carbide Corporation
3. Sugar Corporation
4. Lluveras Sucesión
5. Albert Cage
6. Diego García
7. Jerónimo Lluveras
8. Mercedes Lluveras
9. Hermanas Lluveras
10. Fernando Gilormini

Table 6

Accumulative Energy Cost for Established Users After the Establishment of New Users ($/Yr)

	ESTABLISHED USERS*									
Year	1	2	3	4	5	6	7	8	9	10
1	13319	36834	11497	77892	4273	3762	1281	4989	2954	40581
2	26637	73668	22993	155783	8546	7524	2562	9977	5907	81162
3	39956	110502	34490	233675	12819	11287	3843	14966	8861	121743
4	53274	147335	45986	311566	17092	15048	5123	19955	11814	162324
5	66593	184169	57483	389458	21364	18812	6405	24943	14768	202905
6	79911	221003	68980	467349	25637	22572	7687	29932	17721	243486
7	93230	257837	80476	545241	29910	26334	8967	34921	20675	284067
8	106548	294671	91973	623132	34183	30097	10248	39909	23629	324648
9	119867	331505	103469	701024	38456	33858	11531	44898	26582	365229
10	133185	368338	114966	778915	42729	37621	12809	49887	29536	405810
11	146504	405172	126463	856807	47001	41382	14091	54875	32489	446392
12	159822	442006	137959	934698	51275	45144	15372	59864	35443	486973
13	173141	478840	149456	1012590	55548	48904	16653	64853	38396	527554
14	186459	515674	160953	1090481	59821	52667	17934	69841	41350	568135
15	199778	552508	172449	1168373	64093	56431	16212	74830	44304	608716

* Users

1. Pittsburg Plate Glass
2. Union Carbide Corporation
3. Surgar Corporation
4. Lluveras Sucesión
5. Albert Cage
6. Diego García
7. Jerónimo Lluveras
8. Mercedes Lluveras
9. Hermanas Lluveras
10. Fernando Gilormini

Table 7

Accumulative Energy Cost Differences to Established Users Generated by New Users ($/Yr)

	ESTABLISHED USERS*									
Year	1	2	3	4	5	6	7	8	9	10
1	8867	28840	5224	55591	1035	929	472	1751	1740	33296
2	17733	57681	10446	111181	2070	1858	943	3501	3479	66591
3	26600	86521	15670	166772	3105	2787	1415	5252	5218	99887
4	35465	115361	20892	222361	4140	3715	1885	7003	6957	133183
5	44332	144201	26116	277952	5174	4646	2358	8753	8697	166479
6	53198	173041	31339	333542	6210	5573	2830	10505	10436	199774
7	62065	201882	36562	389133	7245	6502	3301	12256	12175	233070
8	70931	230722	41785	444723	8280	7432	3772	14006	13915	266366
9	79798	259563	47008	500314	9315	8359	4246	15757	15654	299661
10	88664	288402	52231	555904	10350	9289	4714	17508	17394	332957
11	97531	317242	57455	611494	11385	10217	5187	19258	19133	366254
12	106396	346083	62678	667084	12420	11146	5658	21009	20872	399549
13	115263	374923	67901	722675	13455	12073	6130	22760	22611	432845
14	124129	403764	73125	778265	14490	13003	6601	24510	24351	466141
15	132996	432604	78347	833856	15524	13933	7080	26261	26091	499437

* Users

1. Pittsburg Plate Glass
2. Union Carbide Corp.
3. Surgar Corporation
4. Lluveras Sucesión
5. Albert Cage
6. Diego García
7. Jerónimo Lluveras
8. Mercedes Lluveras
9. Hermanas Lluveras
10. Fernando GIlormini

The cost of energy incurred by established users before the new water users established are shown on Table 5 and varies from a low of $809 for Jerónimo Lluveras to $22,301 for Sucesión Lluveras for the first year. Because no change in the price of energy was assumed, the costs of energy incurred by each established user over the fifteen year period increased each year by an amount more or less equivalent to that incurred in the first year. Obviously, since the price of energy will most likely increase in future years, the model can be adjusted to accomodate any such increases or changes in energy costs to established users.

With the establishment of new water users the energy costs incurred by established users are expected to increase over the designated planning horizon of fifteen years. The level of energy costs will depend among other factors, upon the price of energy, well depth, and the rate of pumping. As shown on Table 6, energy costs increased from a low $1281.00 for Jerónimo Lluveras to a high of $77,892.00 for Lluveras Sucesión annually. Compared to energy costs before establishment of new users, these increases represent a 58.3 percent for Jerónimo Lluveras and a 250.0 percent for Lluveras Sucesión during the first years. Increases for other established well owners during the first year are as follows: Pittsburg Plata Glass about 200.0 percent; Union Carbide Corporation 360.8 percent; Sugar Corporation 83.3 percent; Albert Cage 32.0 percent; Diego García 32.8 percent; Mercedes Lluveras 54.1 percent; Hermanas Lluveras 140.3 percent and Fernando Gilormini 457.0 percent.

A significant aspect of cost increases is the accumulated amount each established well is likely to incur over the fifteen year time-period (Table 7). Accordingly, the highest accumulative increases during the time period would be realized as expected by Lluveras Sucesión ($833,856.00) while the lowest ($7,080.00) was incurred by Jerónimo Lluveras. Significant amounts of payment by new users will entile $432,604.00 to Union Carbide Corporation and $499,437.00 to Fernando Gilormini. These payments can constitute a heavy economic burden on prospective users especially since the time-period is relatively short. Obviously, if these payments can be afforded, such costs will be reflected in the prices of goods and services produced by new pumpers and sold to consumers. Therefore, the external costs in the form of energy ultimately will be passed on to consumers who have to pay higher prices for commodities purchased. Obviously by how much prices of commodities can rise will depend on the elasticity of supply and demand for the product in question. Since the external costs incurred related only to the use of energy one can safely state that these costs are less that established users are likely to realize. These costs can be higher because as the water depth falls, additional pumping cost may not reflect itself only in the user of energy but in additional outlay in equipment and materials to the established user.

Interpretation of the results stated herein must relate itself to the question of the time period necessary to remain or be classified as a new user. This study, as mentioned previously assumed a period of fifteen years. This is an arbitrary assumption and becomes more complex when consideration is given to the fact that water-use by both established and new users do affect each other. Sometimes an established user may decide to increase the quantity of water pumped after a "new" user was already established, say ten years already. The additional pumping of the established user certainly will create an external cost on the "new" user and consequently financial compensation must be provided accordingly.

Apart from this problem, the level of the external costs generated by the new user will depend on his radius of influence on the established user. Actually this radius will determine the location of the new user since it measures the distance from the center of the well to the limit of the cone of depression of the well. Knowledge and influence of this radious will serve to minimize the level of external costs on adjacent well and correspondingly the respective compensation to the established user.

To determine the impact of the radius of influence it was assumed that one well was established (QQ) while the other was to be established i.e. a new well (Q). For both wells three flows were considered: 20,000 ft^3/day; 60,000 ft^3/day and 100,000 ft^3/day. Nine alternatives were examined:

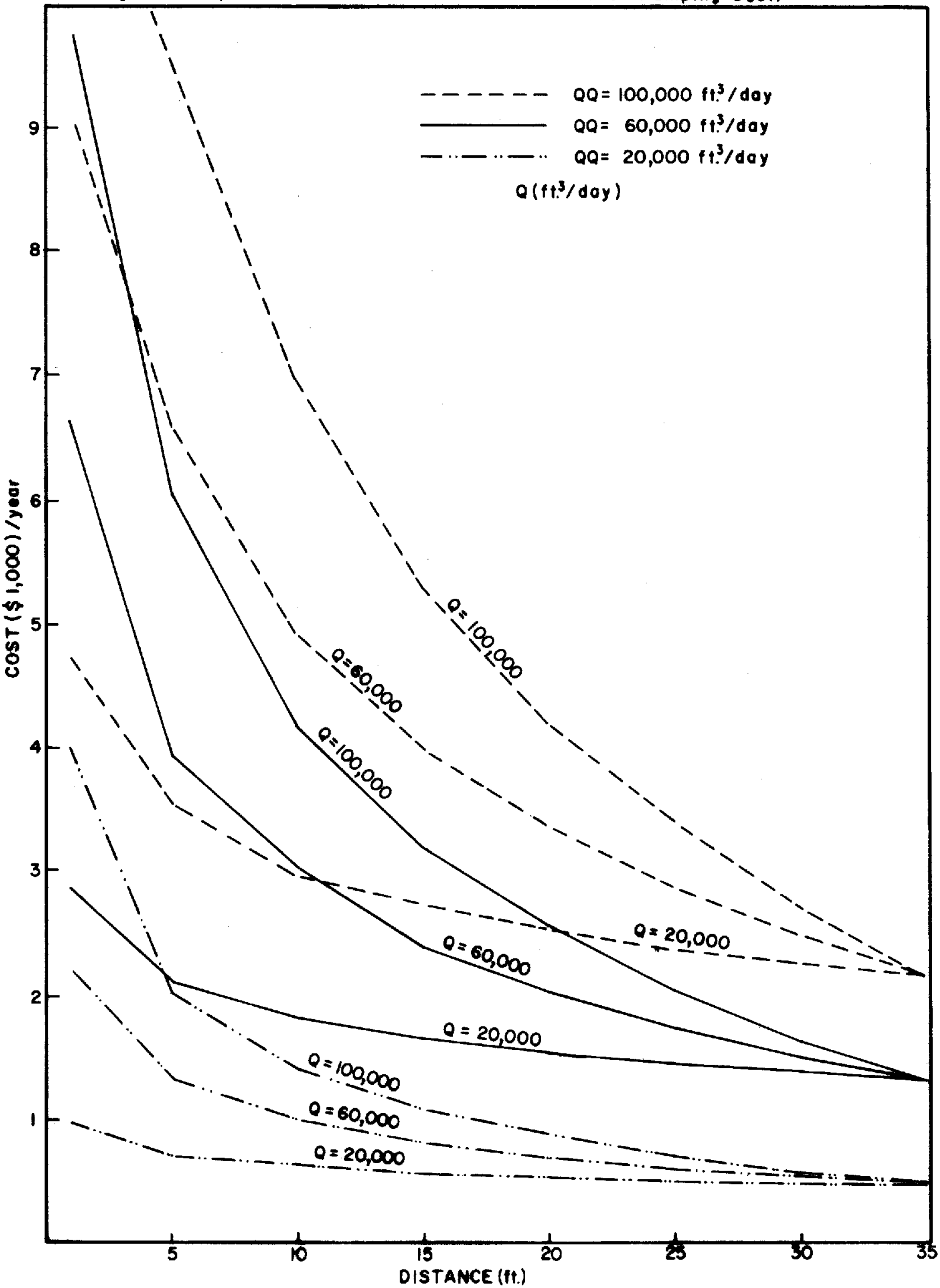
Alternative	Flow of Established Well (WW)	Flow of New Well (Q)
1	20,000 cubic ft/day	20,000 cubic ft/day
2	20,000 " "	60,000 " "
3	20,000 " "	100,000 " "
4	60,000 " "	20,000 " "
5	60,000 " "	60,000 " "
6	60,000 " "	100,000 " "
7	100,000 " "	20,000 " "
8	100,000 " "	60,000 " "
9	100,000 " "	100,000 " "

For each alternative the position of the new well was varied by a distance ranging between 100 feet to 3500 feet from the established well. The results are shown on Fig. 5 where each curve represents a combined flow for both the established and new well.

On the basis of these results the following conclusions can be made:

(1) the greater the quantity of water extracted by the new well, pumping cost were higher for the established well, i.e. additional pumping costs were incurred.

Figure 5. Graph: Radius of the Influence of Distance on Pumping Cost.



(2) the greater the distance between the two wells the additional pumping cost was correspondingly less for the established user, and

(3) when the distance is greater than the radius of influence (3,500 ft in this study) no additional pumping cost was incurred, i.e. the established pumper incurred his normal or regular pumping cost.

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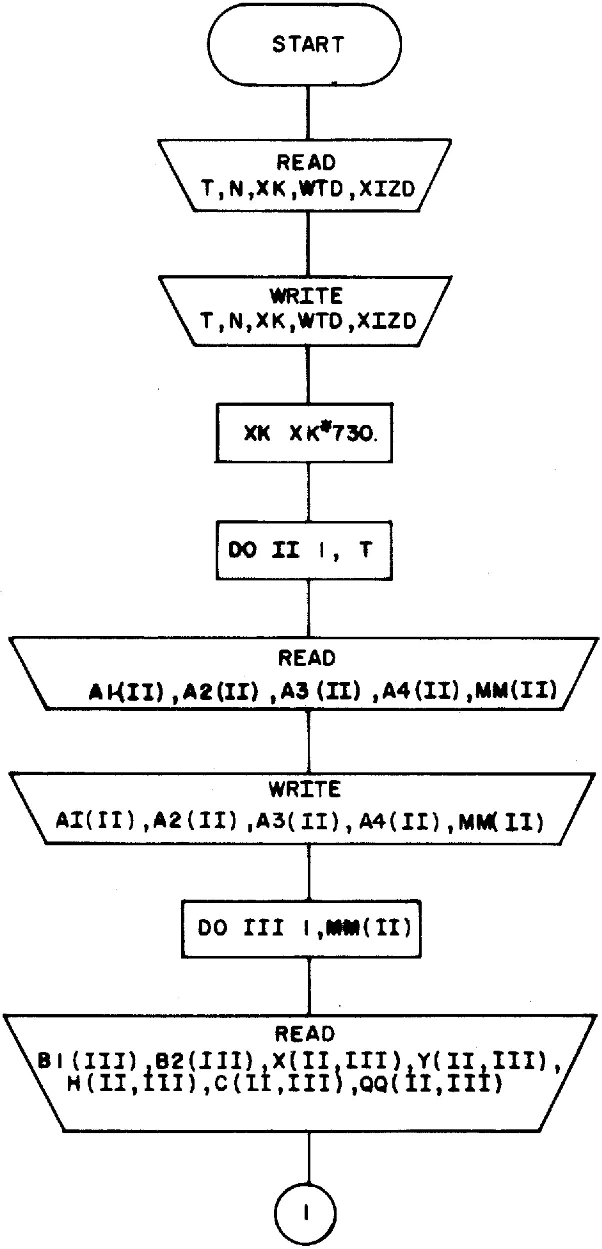
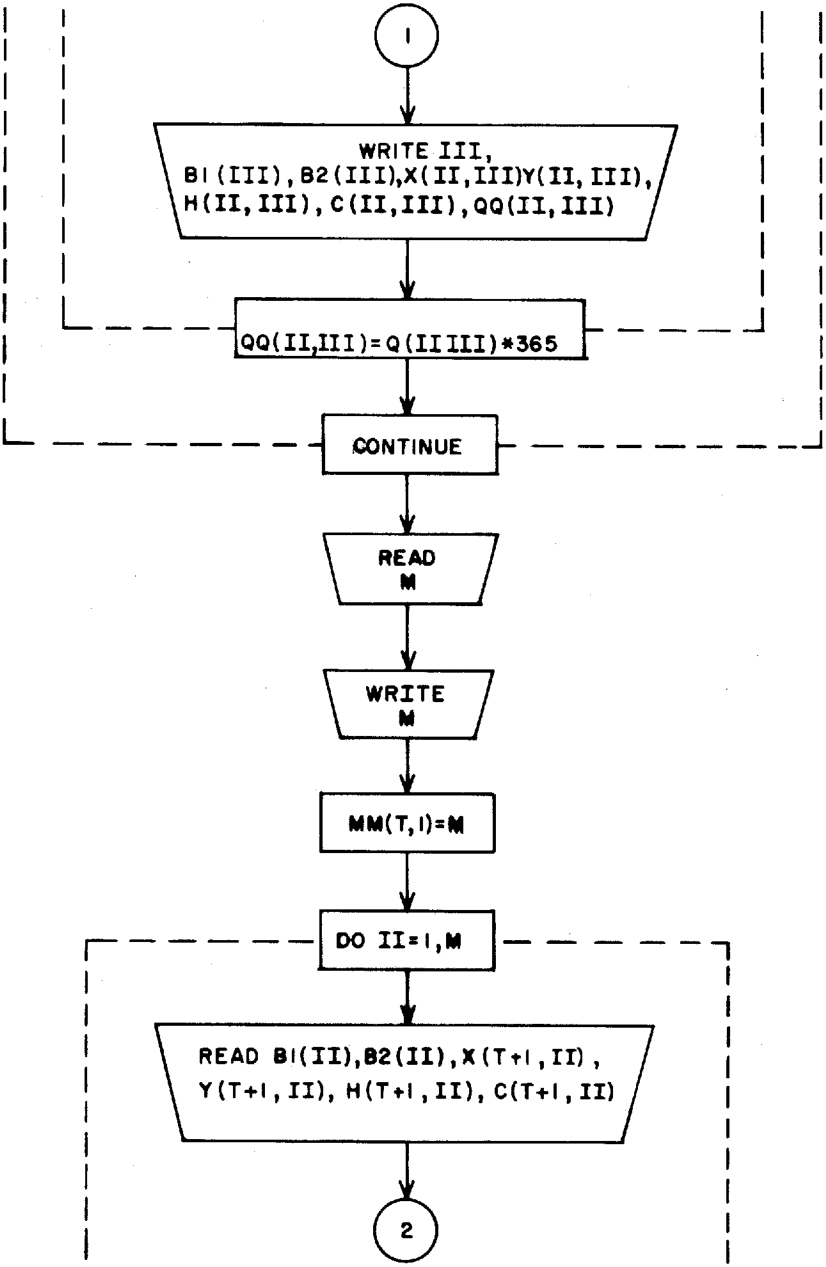
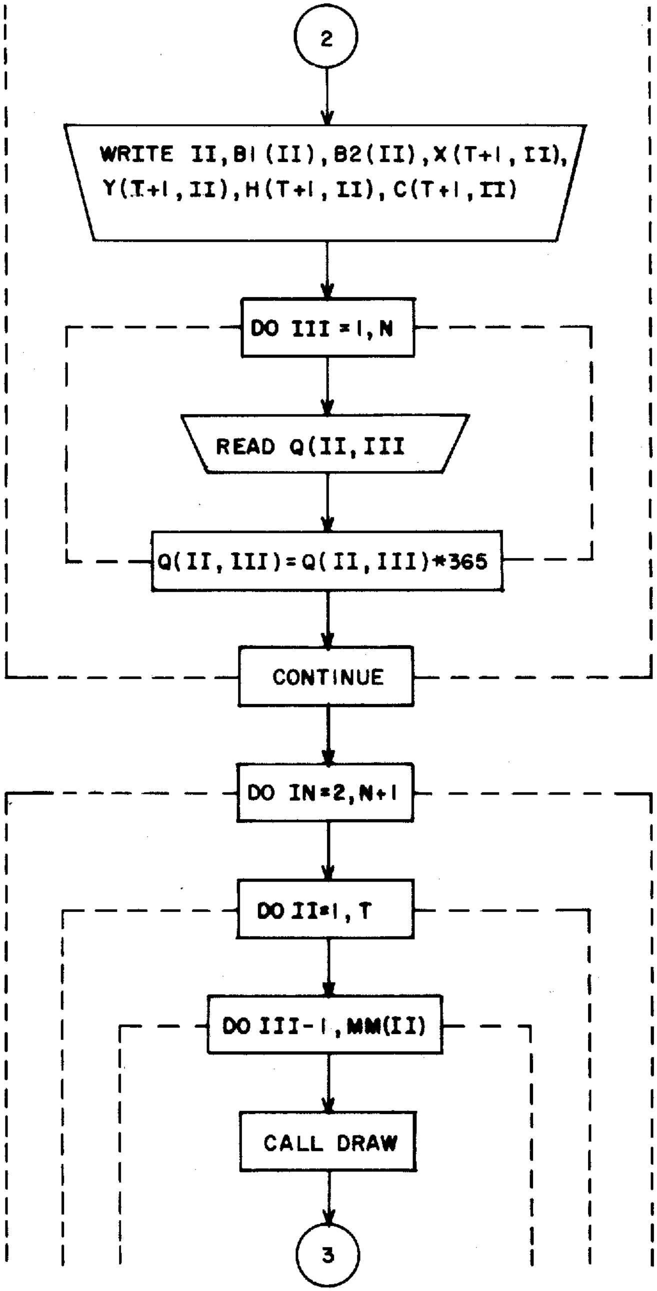
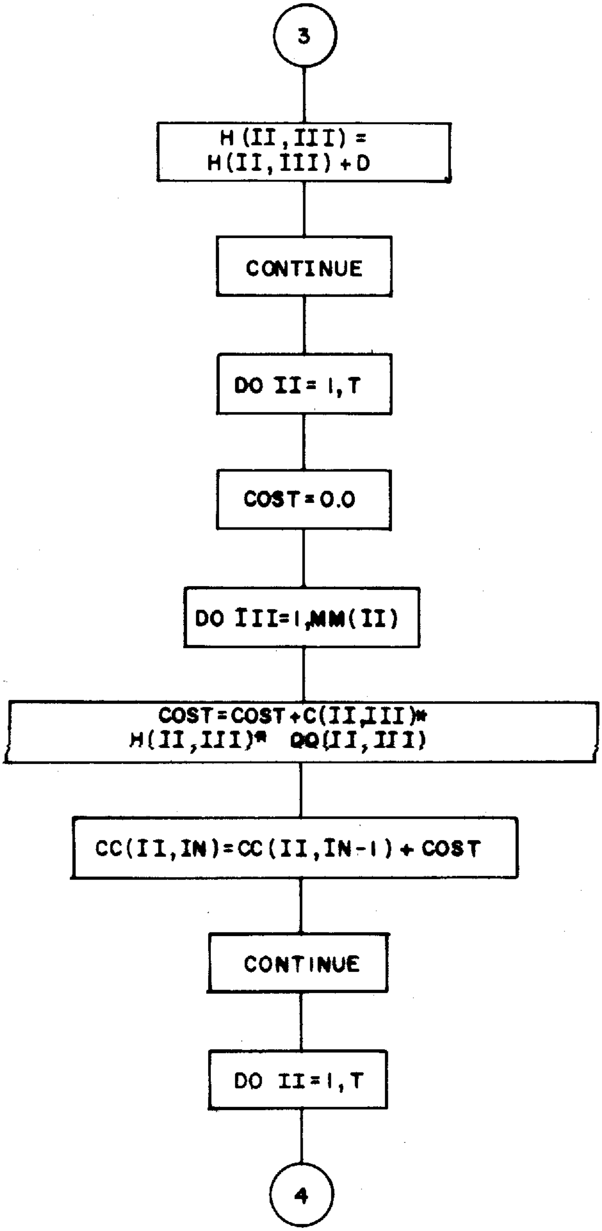
APPENDIX

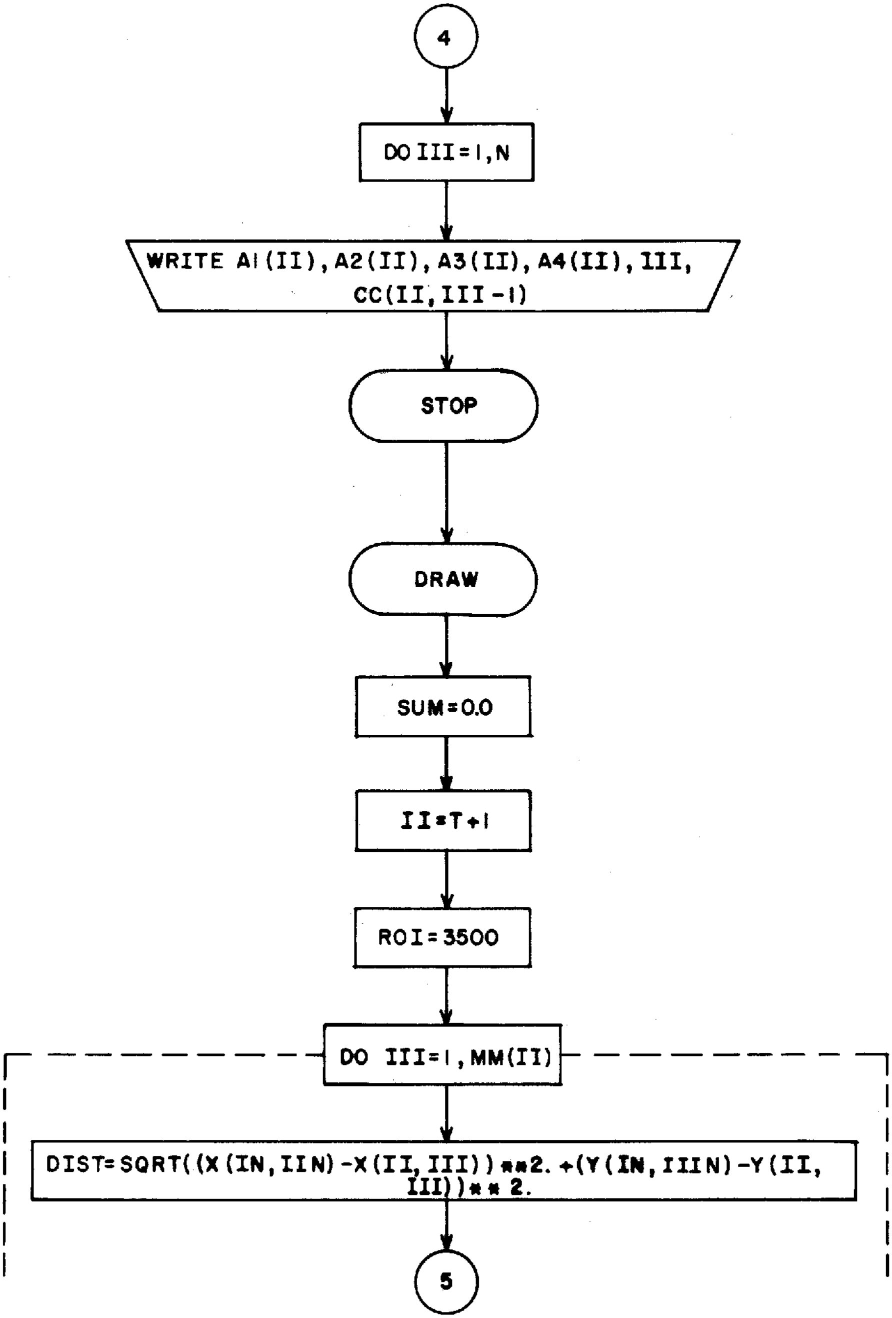
APPENDIX 1

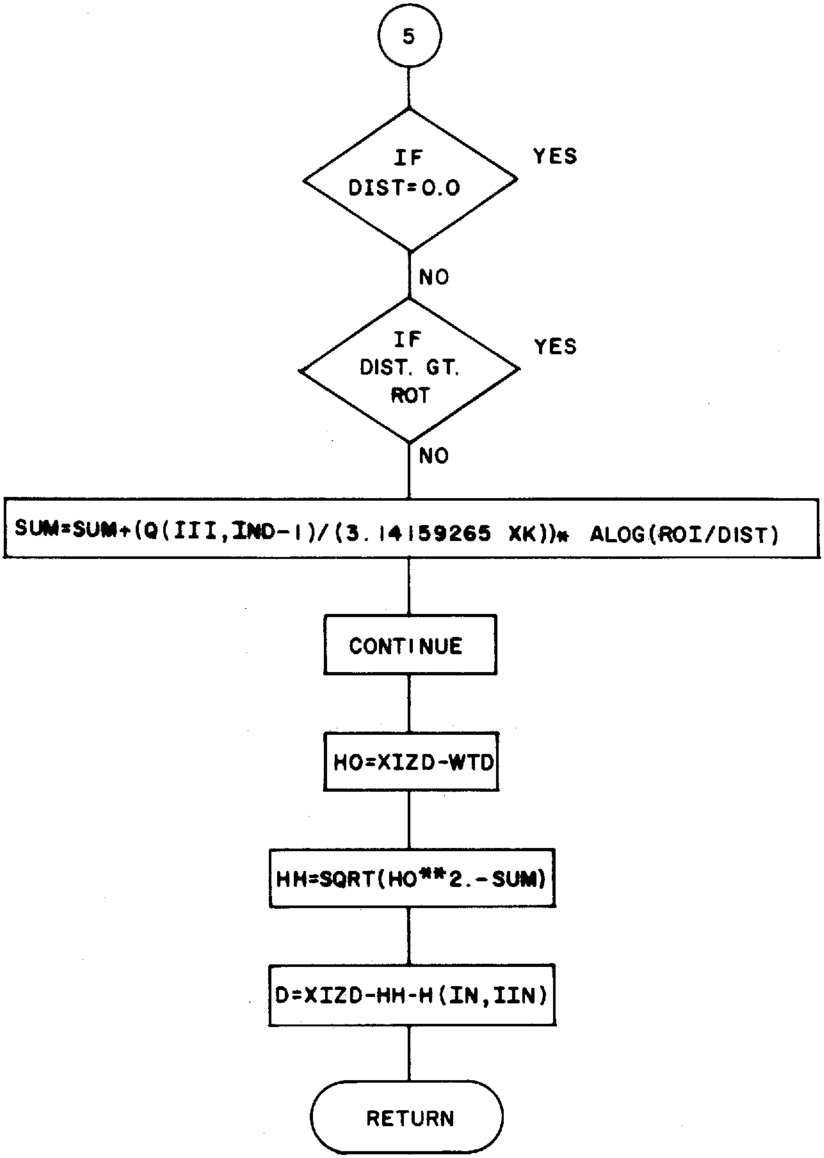

START
READ
T,N,XK,WTD,XIZD
WRITE
T,N,XK,WTD,XIZD
XK XK*730.
DO II I, T
READ
AI(II),A2(II),A3(II),A4(II),MM(II)
WRITE
AI(II),A2(II),A3(II),A4(II),MM(II)
DO III I,MM(II)
READ
BI(III),B2(III),X(II,III),Y(II,III),
H(II,III),C(II,III),QQ(II,III)
I


1
WRITE III,
B1 (III), B2 (III),X(II,III)Y(II, III),
H(II, III), C(II,III), QQ(II, III)
QQ(II,III)=Q(IIIII)*365
CONTINUE
READ
M
WRITE
M
MM(T,1)=M
DO II=1,M
READ B1(II),B2(II),X(T+1,II),
Y(T+1, II), H(T+1, II), C(T+1, II)
2


2
WRITE II,B1(II),B2(II),X(T+1,II),
Y(T+1,II),H(T+1,II),C(T+1,II)
DO III=1,N
READ Q(II,III
Q(II,III)=Q(II,III)*365
CONTINUE
DO IN=2,N+1
DO II=1,T
DO III-1,MM(II)
CALL DRAW
3


3
H(II,III) =
H(II,III) + D
CONTINUE
DO II = 1,T
COST = 0.0
DO III=1,MM(II)
COST = COST + C(II,III)*
H(II,III)* QQ(II,III)
CC(II,IN) = CC(II,IN-1) + COST
CONTINUE
DO II = 1,T
4


4
DO III=1,N
WRITE A1(II),A2(II),A3(II),A4(II),III, CC(II,III-1)
STOP
DRAW
SUM=0.0
II=T+1
ROI=3500
DO III=1,MM(II)
DIST=SQRT((X(IN,IIN)-X(II,III))**2.+(Y(IN,IIIN)-Y(II, III))**2.
5


5
IF DIST=0.0
YES
NO
IF DIST. GT. ROT
YES
NO
SUM=SUM+(Q(III,IND-1)/(3.14159265 XK))* ALOG(ROI/DIST)
CONTINUE
HO=XIZD-WTD
HH=SQRT(HO**2.-SUM)
D=XIZD-HH-H(IN,IIN)
RETURN

APPENDIX 2

```
C ASSUMPTIONS:
C 1. A NEW USER REQUIRES Q(CUB. FT./YR.) FOR N YEARS.
C 2. A WATER RIGHTS STRUCTURE EXIST W/ANNUAL QUOTAS TO EACH
C    USER
C 3. THE AQUIFER IS ABLE TO SUPPLY THE NEW USER FOR N YEARS.
C 4. THE NEW WATER RIGHT WILL INCREASE THE LIFT FOR ALL
C    EXISITNG USERS, DISRUPTING THE ECONOMIC BASIS THAT
C    PRODUCED THE QUOTA SYSTEM.
C 5. WITHDRAWALS PRODUCE DRAWDOWNS THAT ARE SMALL RELATIVE
C    TO SATURATED THICKNESS OF THE AQUIFER
C 6. ALL WELLS ARE FULLY PENETRATING, HENCE A LINEAR RELATION
C    BETWEEN PUMPING AND DRAWDOWN EXISTS
C    NOTATION:
C 1. NEW USER WANTS TO DRILL M WELLS
C 2. THERE ARE T EXISTING USERS
C 3. C(K,T)= ENERGY COST ($/CUB.FT./FT. OF LIFT) FOR THE
C    KTH.WELL OF THE TTH. USER
C 4. MM(T)= NUMBER OF WELLS OF TTH USER
C 5. QQ(K,T)= QUOTA FOR KTH WELL OF TTH. USER (CUB.FT./DAY)
C 6. S(K,T,N)=DRAWDOWN OF KTH WELL OF TTH USER AT END
C    OF NTH. TIME PERIOD.
C 7. H(K,T)= INITIAL LIFT AT KTH. WELL OF TTH. USER PLUS ANY
C    DRAWDOWN DUE TO PREVIOUS PUMPING (FT)
C 8. D(K,T,KK,TT,N)= DRAWDOWN AT KTH WELL OF TTH
C    USER DUE TO PUMPING FROM THE KKTH WELL OF THE TTTH USER
C    FOR YEAR N
C 9. CC(T,N)= ENERGY COST TO THE TTH USER AT END OF THE NTH
C    YEAR
C 10. B(K,T,K*,N*,N)= INCREMENT OF DRAWDOWN AT KTH WELL
C    OF TTH USER AT THE END OF YEAR N DUE TO
C    A UNIT PUMPING AT THE NEW USERS K* WELL DURING YEAR N*
C 11. Q(J*,N)= WITHDRAWAL FROM J* NEW WELL IN YEAR N (CUB.
C    FT./DAY) COMMON X(50,20), Y(50,20), MM(50), H(50,20),
     C(50,20),QQ(50,20), 1Q (20,50), CC(50,50), T,XK,WTD,
     XIDZ
     DIMENSION A1(50), A2(50), A3(50),A4(50),B1(20),B2(20)
     INTEGER T
C
C    PROGRAM IS SET FOR A MAXIMUM OF 20 WELL PER USER, 50
C    USERS TOTAL
C    READ EXISTING CONDITIONS
```

```
C     READ NUMBER OF USERS PLANNING HORIZON (LESS THAN 50
C     YEARS), PERMEABILITY, WATER TABLE DEPTH,IMPERVIOUS
C     ZONE DEPTH
C
      READ (2,1) T,N,XK,WTD, XIZD
    1 FORMAT (215,3F 10.3)
      WRITE (3,13) T,N,XK,WTD,XIZD
   13 FORMAT (1X,//,10X,NUMBER OF USERS-- , 1X,15,/,10X,
      PLANNING HORIZ
    1 ON-- , 1X,13, YEARS , /, 10X, PERMEABILITY-- , F10.3,
       (IN/HR)
    2, /,10X, WATER TABLE DEPTH -- , F5.2, FT./,10X, IMPERVIOUS
    3 ZONE DEPTH-- , F10.3, FT,///)
      XK=XK*730.
C
C     FOR EACH USER, READ ITS SPECIFICATIONS
      DO 2 II=1,T
C
C     READ NUMBER OF WELLS FOR USER II
      READ (2,3) A1(II),A2(II),A3(II),A4(II),MM(II)
    3 FORMAT (4A5,15)
      WRITE (3,15) II, A1(II),A2(II),A3 (II), A4(II),MM(II)
   15 FORMAT (1X,//,2X, USER NO. 1X,I2, :  , 4A5,   WITH ,I3,
     1  WELLS ,/)
      WRITE (3,16)
   16 FORMAT (5X,WELL NAME , 4X, X(FT), 5X,  Y(FT) ,2X, INITIAL
    1 LIFT (FT) ,2X, ENERGY COST ($/CUB.FT./FT) , 2X, QUOTA
      CUB.FT. 2/YR)  ,/)
C
      DO 25 III=1,MM(II)
C
C     READ GEOGRAPHICAL LOCATION, INITIAL DRAW DOWN, ENERGY
      COST, QUOTA
      READ (2,4) B1(III),B2(III), X(II,III),Y(II,III),H(II,
     1III), C(II,III),QQ(II,III)
      WRITE (3,18) III,B1(III),B2(III), X(II,III),Y(II,III),
      H(II,III),
     1C(II,III),QQ(II,III)
   18 FORMAT (1X,I2,1X,2A5,1X,2F10.3,2X,F10.3,13X,F10.8,11X,
      F10.3)
      QQ(II,III)-QQ(II,III)* 365.
   25 CONTINUE
    2 CONTINUE
```

```
    4 FORMAT (2A5, 3F10.3, F10.8,F10.3)
C       BRING IN NEW USER
C
C       READ NEW USER (T+1) SPECIFICATIONS, FOR THE N YEARS
        READ (2,26) M,A
   26 FORMAT (2I5)
        WRITE (3,19) M
   19 FORMAT (1X,///,5X, NEW USERS HAS  , I5, WELLS ,/)
        WRITE (3,30)
   30 FORMAT (5X, WELL NAME , 4X, X(FT) ,5X, Y(FT) , 2X,
        INITIAL
    1 LIFT (FT) , 2X, ENERGY COST (CUB.FT./FT.) )
        MM(T+1)=M
        DO 12 II=1,M
        READ (2,20) B1(II),B2(II),X(T+1,II), X(T+1,II),Y(T+1,
        II),H(T+1,II),C(T+1,II)
   20 FORMAT (2A5,3F10.3, F10.8)
        WRITE (3, 21) II, B1(II),B2(II),X(T+1,II),Y(T+1,II),
        H(T+1,II),
    1 C(T+1,II)
  21  FORMAT (1X,I2,2A5,1X,2F10.3,2X,F10.3,13X,F10.8)
C
C       READ THE REQUIREMENTS FOR II WELL FOR THE NTH YEAR
         IF (A.EQ.1)GO TO 5
         DO 5 III= 1,N
         READ (2,6) Q(II,III)
   5     Q(II,III)=Q(II,III)*365.
   6     FORMAT (F10.3)
  12     CONTINUE
C       YEARS ARE ONE MORE THAN REAL BECAUSE  OF ZERO SUBSCRIPT
         DO 8 IN=2,N+1
         DO 7 II= 1,T
         DO 7 III=1,MM(II)
         CALL DRAW (II,III,D,IN)
   7     H(II,III)=H(II,III)+ D
C
C       CALCULATE ENERGY COST FOR EACH USER AT END OF THIS
        YEAR
         DO 8 II=1,T
         COST= 0.0
         DO 9 III=1,MM(II)
         COST= COST+C(II,III)*H(II,III)*QQ(II,III)
   9     CONTINUE
```

```
  8 CC(II,IN)=CC(II,IN-1)+COST
    WRITE (3,22)
 22 FORMAT (1X,////,20X, R E S U L T S  , //)
    DO 10 II=1,T
    DO 10 III=1,N
 10 WRITE (3,23) A1(II),A2(II),A3(II),A4(II),III,CC(II,
    III+1)
 23 FORMAT (3X, USER= , 4A5,   YEAR=  , I5,    COST= ,
    F 12.0)
    STOP
    END
    SUBROUTINE DRAW (IN,IIN,D,IND)
    COMMON X(50,20),Y(50,20),MM(50),H(50,20),C(50,20),
    QQ(50,20),
  1 Q(20,50),CC(50,50),T,XK,WTD,XIDZ
    INTEGER T
    SUM=0.0
    II=T+1
    ROI=3500.
    DO 1 III=1,MM(II)
    DIST=SQRT(X(IN,IN)-X(II,III))**2.+(Y(IN,IIN)-Y(II,III))
    **2.)
    IF (DIST.EQ.0.0)GO TO 1
    IF (DIST.GT.ROI)GO TO 1
    SUM=SUM+(Q(III,IND-1)/(3.14159265*XK))*ALDG(ROI/DIST)
  1 CONTINUE
    HO= XIDZ-WTD
    HH= SQRT(HO**2.-SUM)
    D=XIDZ-HH-H(IN,IIN)
    RETURN
    END
```

APPENDIX 3

```
         NUMBER OF USERS--     10
         PLANNING HORIZON--  15 YEARS
         PERMEABILITY--      5.000(IN/HR)
         WATER TABLE DEPTH-- 8.00 FT
         IMPERVIOUS ZONE DEPTH--   125.000 FT



USER NO. 1 : P.P.G. INDUSTRIES      WITH  3 WELLS

   WELL NAME      X(FT)       Y(FT)  INITIAL LIFT(FT)  ENERGY COST($/CUB.FT./FT)

1 P.P.G. 2      3800.000 20667.000        65.000                .00000720
2 P.P.G. 1      4700.000 20133.000        70.000                .00000720
3 P.P.G. 5      3100.000 20333.000        57.500                .00000720

USER NO. 2 : UNION CARBIDE CARIBE   WITH  5 WELLS

   WELL NAME      X(FT)       Y(FT)  INITIAL LIFT(FT)  ENERGY COST($/CUB.FT./FT)

1 U.C. 1201     5667.000 17667.000        34.500                .00000720
2 U.C. 1202     6967.000 15233.000        73.000                .00000720
3 U.C. 1211     5900.000 12700.000        62.000                .00000720
4 U.C. 1213     6867.000 12167.000        62.000                .00000720
5 U.C. 1212     7400.000 11100.000        62.000                .00000720

USER NO. 3 : CORP. AZUCARERA        WITH  3 WELLS

   WELL NAME      X(FT)       Y(FT)  INITIAL LIFT(FT)  ENERGY COST($/CUB.FT./FT)

1 C.A. 36       3867.000  6800.000        35.000                .00000720
2 C.A. 21       7067.000 17533.000        30.000                .00000720
3 C.A. 27       4867.000 13667.000        35.000                .00000720

USER NO. 4 : SUCESION LLUVERAS      WITH 11 WELLS

   WELL NAME      X(FT)       Y(FT)  INITIAL LIFT(FT)  ENERGY COST($/CUB.FT./FT)

 1 S.LL. 41      6433.000  6333.000       35.000                .00000720
 2 S.LL. 44     11633.000  4833.000       35.000                .00000720
 3 S.LL. 45     11333.000  4067.000       35.000                .00000720
 4 S.LL. 48A    12533.000  3900.000       35.000                .00000720
 5 S.LL. 48B    12567.000  3567.000       35.000                .00000720
 6 S.LL. 48C    13300.000  3433.000       35.000                .00000720
 7 S.LL. 48D    12100.000  3667.000       35.000                .00000720
 8 S.LL. 49     10767.000  6233.000       35.000                .00000720
 9 S.LL. 50     11933.000  6667.000       35.000                .00000720
10 S.LL. 51     12767.000  6600.000       35.000                .00000720
11 S.LL. 52     13767.000  7300.000       35.000                .00000720

USER NO. 5 : ALBERT C. CAGE         WITH  1 WELLS
```

```
   WELL NAME     X(FT)      Y(FT)   INITIAL LIFT(FT)   ENERGY COST($/CUB.FT./FT)

 1 CAGE 34      6133.000  9000.000      35.000                    .00000720

USER NO. 6 : DIEGO ROCA              WITH  1 WELLS

   WELL NAME     X(FT)      Y(FT)   INITIAL LIFT(FT)   ENERGY COST($/CUB.FT./FT)

 1 ROCA 37      4967.000  6833.000      35.000                    .00000720

USER NO. 7 : JERONIMO LLUVERAS       WITH  1 WELLS

   WELL NAME     X(FT)      Y(FT)   INITIAL LIFT(FT)   ENERGY COST($/CUB.FT./FT)

 1 J.LL. 40     5733.000  5933.000      35.000                    .00000720

USER NO. 8 : MERCEDES LLUVERAS       WITH  1 WELLS

   WELL NAME     X(FT)      Y(FT)   INITIAL LIFT(FT)   ENERGY COST($/CUB.FT./FT)

 1 M.LL. 42     9167.000  5433.000      35.000                    .00000720

USER NO. 9 : HERMANAS LLUVERAS       WITH  1 WELLS

   WELL NAME     X(FT)      Y(FT)   INITIAL LIFT(FT)   ENERGY COST($/CUB.FT./FT)

 1 H.LL. 33     5933.000 10533.000      30.000                    .00000720

USER NO.(10): FERNANDO GILORMINI     WITH  2 WELLS

   WELL NAME     X(FT)      Y(FT)   INITIAL LIFT(FT)   ENERGY COST($/CUB.FT./FT)

 1 F.G. 26      5567.000 14633.000      35.000                    .00000720
 2 F.G. 30      7233.000 11733.000      30.000                    .00000720


   NEW USERS HAS    6 WELLS

   WELL NAME     X(FT)      Y(FT)   INITIAL LIFT(FT)   ENERGY COST(CUB.FT./FT)
 1        NW 1  10500.000  4200.000    35.000                    .00000720
 2        NW 2  12200.000  6200.000    35.000                    .00000720
 3        NW 3   6500.000 11800.000    62.000                    .00000720
 4        NW 4   6200.000 14200.000    35.000                    .00000720
 5        NW 5   6500.000 16800.000    62.000                    .00000720
 6        NW 6   3800.000 20000.000    65.000                    .00000720
```

```
                  R E S U L T S

 USER= P.P.G. INDUSTRIES      YEAR=     1  COST =          13319.
 USER= P.P.G. INDUSTRIES      YEAR=     2  COST =          26637.
```