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ECONOMIC ASPECTS OF IRRIGATION FROM GROUND WATER

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16. Abstracts Typical examples of economic analysis of ground water development in Brazil are discussed, citing specific data for Bolivian conditions with conversion to Cruzeiro values, but without a detailed knowledge of commodity prices and costs in Brazil. Utilization of ground water can produce both irrigation and drainage benefits -- pumping from underground reservoirs has alleviated many drainage problems. Typical irrigation systems were selected, designs developed, and costs estimated. From theoretical considerations, and from available crop, moisture - yield relationships developed in other areas, the supply of adequate moisture properly distributed throughout the growing season should at least double production for cotton, sugar cane, soy beans, wheat, forage crops, and others with similar water requirements. Irrigation costs are analyzed. Estimates of the internal rate of return -- a procedure which expresses rates of return as a percentage which can be compared with the rate of interest charged in the capital market -- were made for all single and double crop situations under two irrigationn systems. The two systems are the sprinkler and the

17. Key Words and Document Analysis. 17a. Descriptors surface irrigation. In areas with limited ground water recharge, it is suggested that the most economical use of ground water would be mining the results over a period of fifteen to twenty years. Economic analysis based on the Santa Cruz, Bolivia area appears to apply to conditions in the semi-arid areas of Brazil.

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ECONOMIC ASPECTS OF IRRIGATION FROM GROUND WATER

By George H. Hargreaves[1]

INTRODUCTION

Success or failure in many investments depends to a large degree upon the capabilities of management. Successful ground water development depends upon many factors. In the Philippines success or failure of projects in a pump irrigation program depended to an important degree upon proximity of qualified mechanics, repair facilities and stocks of spare parts. Success was greatly increased through governmental initiative in locating mechanics and spares so that repair services could be readily available.

Various studies have emphasized the importance of safe yield or sustained yield in the development of ground water resources. However, uncontrolled mining of ground water has in many instances paved the way for large and economically desirable surface water developments.

Knowledge and experience gained from ground water development is sometimes a prerequisite to the success of large surface water projects. These initial or pilot developments may produce economic benefits that are long range but difficult to visualize or evaluate at the time of ground water development planning.

This paper shows some typical examples of economic analysis of ground water development. It is, however, written without a detailed knowledge of commodity prices and costs in Brazil. It does cite specific data for Bolivian conditions with conversion to Cruzeiro values.

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In determining safe yields for the groundwater basins of Northeastern Brazil, Gaspary and Reboucas, as cited by Souto Maior (3)[2], used a maximum economic pump lift of 150 meters and a drilling limit of 1,000 meters of depth. The economics of various different water use developments were not analyzed.

A study made by Bolivian-Utah State-USAID Study Team (1) analyzes benefits and costs for pump irrigation for selected crops for the area around Santa Cruz, Bolivia. The economic analysis for the Santa Cruz area is presented in order to illustrate methodology. With suitable modification this procedure can be applied to Brazilian conditions.

Consideration should be given to the relationship of ground water to drainage. In some instances the economic benefits to improved drainage conditions are of considerable magnitude.

PUMPING GROUND WATER FOR DRAINAGE

In many situations utilization of ground water produces both irrigation and drainage benefits. Pumping from underground reservoirs has relieved and alleviated many drainage problems.

The irrigation planning and design for an important portion of the east side of the Central Valley of California was based upon the assumption that about 35 percent of the water used would be pumped from ground water in the interests of minimizing future drainage problems. Milligan (2) cites several instances showing the benefits from pumping ground water for drainage. These are summarized in part in the following paragraphs.

The Modesto Irrigation District in California formerly had 45,000 acres (18,000 hectares) under a system of gravity drainage. This system was replaced by pumping from groundwater with the following comparison.

Item	Costs for Gravity Drains	Costs for Pumping from Ground Water
Construction and Installation	$308,000	$159,000
Operation and Maintenance	148,700	60,050
Power Costs		393,100
Value of Water Produced		612,050

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[2] Number in parentheses refers to corresponding items in the Appendix-References.

After construction the annual costs of the drainage system were $148, 700, while by contrast pumping for both irrigation and drainage accomplished the drainage with an annual profit of $158, 900.

In the Salt River Valley of Arizona, pumping 400, 000 acre-feet annually, or about one-third of the irrigation supply, solved the drainage problem.

The Turlock Irrigation District of California (4) formerly operated a system of open drains. They now use a system of wells to provide drainage as well as irrigation water. A total of 181 pumps are used.

These are but a few examples of possible benefits. Conditions are not universally favorable for combining ground water pumping for irrigation with improvement of drainage conditions. Possible benefits are, however, of such magnitude that this possibility should not be overlooked and advantage taken whenever it appears economically feasible.

IRRIGATION SYSTEMS AND COSTS

Typical irrigation systems were selected, designs were developed and costs estimated. Fixed costs were amortized using an interest rate of 15 percent. The life of various works was estimated as follows:

Well	15 years
Diesel motor	10 years
Deep well pump	10 years
10 HP pump and motor	15 years
Sprinkler laterals and main line	5 years
Ditches and leveling	10 years

The following summary based on a full irrigation supply by sprinkler for sugar cane and an efficiency of 75 percent gives some of the calculations used in developing the estimates. The costs are based upon the assumption that the power source will be diesel and that fuel costs are Cr .3 per liter of diesel fuel, or US$ .19 per gallon.

Maximum monthly net requirement = 120 mm

120 mm/.75 = 160 mm

1 l/sec/Ha pumping 90% of time = 2, 330 m^3/Ha
= 233 mm application

1 l/sec can irrigate 1.45 Ha

50 l/sec irrigates 72.5 Ha

Annual irrigation application for sugar cane is about 650 mm (gross)

72.5 Ha x $10,000 \times .65 = 470,000\ m^3$

50 l/sec = $180\ m^3$/hr

470,000/180 = 2,600 hours pumping

2,600 hrs x 75 BHP x .0155 = $3,020

3,020/72.5 = $41.6/Ha = Cr 250/Ha

Note.—.0155 = handbook factor for fuel cost of US$ .19 per gallon.

Crop	Fuel, Operation and Maintenance Cost
Sugar Cane	Cr 250
Pasture	300
Cotton	112
Soya	88
Wheat	88
Green Manure	75

Wells for Irrigation

Because of the variability that exists in aquifer characteristics from location to location, well yield can be predicted only in general terms.

Based upon the well data assembled, discussions with well drillers, and detailed analysis, the following average conditions will be encountered in drilling irrigation wells.

Flow from Well = 175,000 liters per hour

Flow will vary with drawdown and well characteristics. Specific capacity seems, from the limited data available and from experience of drillers, to average about 7,500 liters per hour per meter of drawdown. Thus, a drawdown of 23 meters will yield an average 175,000 l/hr.

Well Diameter = 12-inch casing

Rotary equipment is used exclusively for well drilling. Irrigation wells should be cased with at least 10-inch diameter pipe and preferably 12- or 14-inch. Larger sizes will be more productive, but under existing conditions the optimum will likely be a 12-inch casing in a 20-inch hole backfilled with properly graded gravel.

Well Depth = 200 meters

On larger projects the first of several wells should be centrally located and drilled to perhaps 250 meters depth to determine the nature of deeper aquifers. The average minimum depth for good irrigation wells will likely be about 200 meters.

Static Depth to Water = 10 meters

Depth to water varies from ground surface in the north to 20 meters and in some areas 30 meters in the south. Deep irrigation wells in the north will encounter artesian conditions. An average depth of 10 meters to water will be assumed.

Power Required = 75 HP

At 70 percent efficiency, 30 horsepower will be required to bring the water 33 meters to the ground surface, and assuming 45 pounds per square inch at the sprinkler, another 45 horsepower is required, necessitating a 75 horsepower unit.

Cost of Well = Cr 120,000

Present costs are about Cr 50 per diameter inch per meter depth. Thus, a 12-inch well drilled to 200 meters will cost Cr 600 per meter, or Cr 120,000 for 200 meters.

Drilling costs for irrigation will reduce with volume and competition. Custom duties on pumps, motors, and pipe are from 25 to 39 percent. Since 75 percent of the cost of a well is materials, the cort of wells should be reduced considerably by reducing import duties.

Cost of Pump = Cr 17,000

Pump would be a deep-well turbine type.

Cost of Power = Cr 15,500 for electrical, Cr 32,500 for diesel

Electrical units are less costly than diesel units and have a longer life. However, since electrical power is not now generally available, diesel units have been considered in estimating irrigation costs. Design data for use in estimating the costs of various types of irrigation systems are summarized in Table 1.

Table 1. Design Data for Irrigation System

WELL DATA		
Diameter	10 to 14 inches	12 inches
Depth of well	150 to 250 meters	200 meters
Discharge	125,000 to 300,000 l/hr	175,000 l/hr
Specific Capacity	5,000 to 10,000 l/hr/m	7,500 l/hr/m
Draw Down	15 to 35 meters	23 meters
Static Level	0 to 30 meters	10 meters
Total Lift	0 to 65 meters	33 meters
Efficiency	65% to 80%	70%
Power required to bring water to ground surface		30 HP
SPRINKLER DATA		
Pressure at sprinkler nozzle		45 psi
Total dynamic head		162 feet
Power required for sprinkling		45 HP
Total power required		75 HP
Area irrigated at 0.67 l/s/ha		75 Ha
COST ESTIMATE		
Well		Cr 120,000
Pump		Cr 17,000
Power Unit: Electrical		Cr 15,500
Power Unit: Diesel		Cr 32,500
Pump house and installation		Cr 14,000

Sprinkler Irrigation

Hand move portable sprinkler laterals are recommended. Labor is available, reliable, and relatively inexpensive. For this reason hand move sprinkler laterals are recommended over mechanical sprinkler equipment. Overall costs of hand move systems are estimated to be significantly less than those for automatic systems.

A water pressure at the sprinkler head of 45 pounds per square inch is recommended. This pressure will assure proper droplot formation and will keep power costs at a minimum.

On rather flat lands the well should be located in the center of the land to be irrigated with two main lines extending out from the well in opposite directions. Portable hand move laterals can be connected to valves in the main line and extended at right angles to the main line. A typical layout is shown in Figure 1 for a rather flat terrain. As slopes increase, the well needs to be placed more toward the upper end of the field so that variation in pressure throughout the lateral system is less than 20 percent of the sprinkler pressure.

Several reasons exist recommending that sprinkler irrigation be used rather than surface irrigation:

1. With lack of management and labor experience with irrigation, sprinklers are easier and more fool-proof to operate.

2. Good production can be obtained the first year using sprinklers. Surface irrigation generally requires from 2 to 3 years before production is satisfactory on new developments.

3. Approximately 50 percent more water is required for surface irrigation unless the land is very well prepared and conveyance ditches have low water losses.

4. Very careful land leveling will be required for the rather flat lands of the study area if surface irrigation is to be used. Equipment and experience for land leveling is lacking.

Annual Costs

Annual costs in cruzeiros per hectare for different types of irrigation developments are given in Tables 2 and 3.

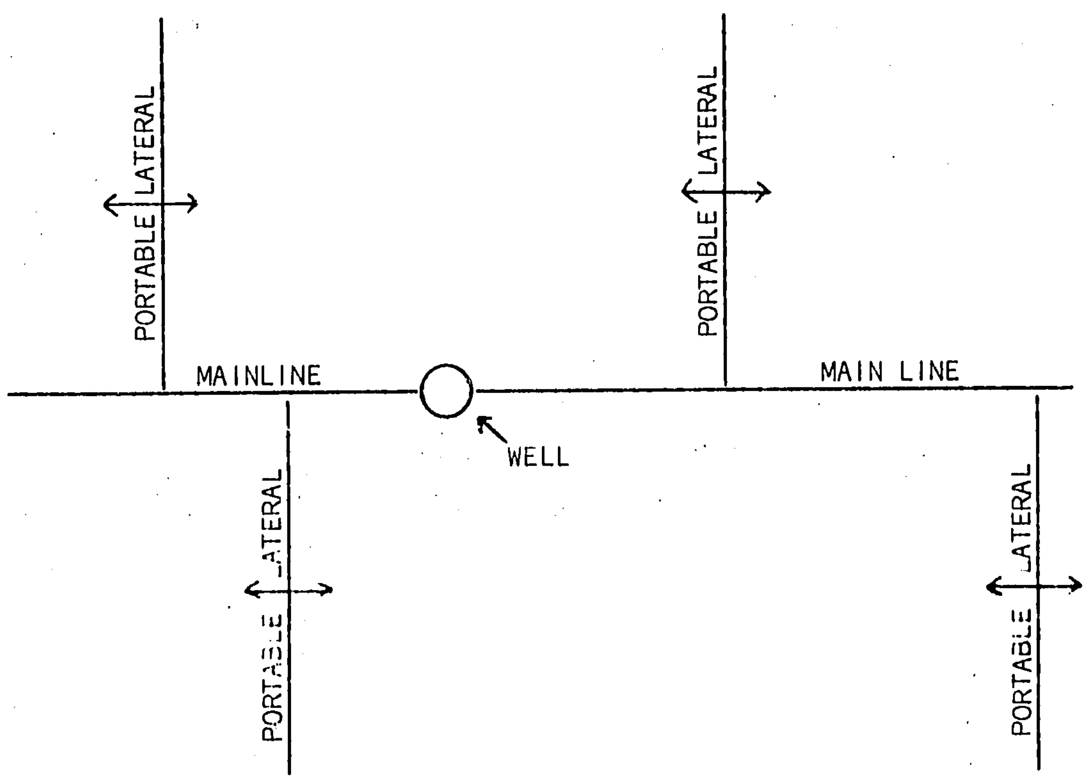

Figure 1. Typical Layout of a Sprinkler Irrigation System

Table 2. Sprinkler Irrigation System from Well in Cruzeiros per Hectare per Year (1)

Crop	Fixed Costs		Operating Costs	Labor	Total
	Well, Pump & Motor	Laterals & Main Line	Fuel. Operation & Maintenance		
Sugar Cane	442	540	250	20	1252
Pasture	442	540	300	25	1307
Cotton	265	325	112	8	710
Soya	178	215	88	8	489
Wheat	178	215	88	8	489
Green Manure	178	215	75	15	483

Table 3. Surface Irrigation System from Well in Cruzeiros per Hectare per Year (2)

Crop	Fixed Costs		Operating Costs	Labor	Total
	Well, Pump & Motor	Ditches & Leveling	Fuel, Operation & Maintenance		
Sugar Cane	660	142	375	60	1237
Pasture	660	142	450	76	1327
Cotton	400	85	268	22	675
Soy	260	58	130	22	470
Wheat	260	58	130	22	470
Green Manure	260	58	112	15	445

Fixed Costs

In order to facilitate flexibility in the computation of costs, the fixed costs per hectare are shown in Tables 4 and 5.

CROP YIELDS, PRODUCTION COSTS AND PROFITS

This analysis is deliberately conservative in order to allow for unforeseen problems and for equipment failure that can at times seriously reduce yields below those possible under optimum conditions.

Table 4. Sprinkler Irrigation System from Well, Fixed Costs in Cruzeiros per Hectare

Crop	Well (15 Year Life)	Pumping Plant (10 Year Life)	Laterals & Main (8 Year Life)
Sugar Cane	1600	845	2425
Pasture	1600	845	2425
Cotton	960	510	1460
Soya	640	340	965
Wheat	640	340	965
Green Manure	640	340	965

Table 5. Surface Irrigation System from Well, Fixed Costs in Cruzeiros per Hectare

Crop	Well (15 Year Life)	Pumping Plant (10 Year Life)	Ditching & Leveling (10 Year Life)
Sugar Cane	2400	1270	715
Pasture	2400	1270	715
Cotton	1440	760	430
Soya	960	505	285
Wheat	960	505	285
Green Manure	960	505	285

Data were furnished by Jaeger relative to yields of cotton in quintales per hectare and of sugar cane in metric tons per hectare at La Victoria and are given in Table 6.

Ing. Fabian Yassie F. of Cooperativa Rural de Electrificacion Ltda. (CRE) made a study relative to irrigation in October 1971. He concluded that the following yields can be obtained per hectare for crops under irrigation:

Table 6. Yield Data Given by Jaeger

Year	Crop	Yield per Hectare				
		No Irrig	6 Irrig	5 Irrig	4 Irrig	3 Irrig
1970-71	Cotton	14.1				29.3
1969-70	Sugar Cane	63.0	149.0	131.0		
1970-71	Sugar Cane	11.0			*72.0	

*Yield reduced due to irrigation equipment failure.

Crop	Yield per Hectare
Sugar Cane	100 - 140 tons
Rice	8 tons
Cotton	25 or more quintales
Wheat	4,000 kg
Pasture	60 AUM

Except for rice and wheat, these projected yields appear quite realistic for well-managed irrigation systems. With fertilization, significantly higher yields are to be anticipated.

From theoretical considerations and from available crop, moisture, yield relationships developed in other areas, the supply of adequate moisture properly distributed throughout the growing season should more than double production for cotton, sugar cane, soy beans, wheat, forage crops and other crops with similar water requirements. This is in an area with a mean annual precipitation of about 1150 mm of which 75 percent occurs during the October through April rainy season. In appraising the economics of crop production or of irrigation development, however, it should be kept in mind that an unforeseen heavy rain soon after planting may greatly reduce yields or result in near failure to establish a good initial stand. The provision of a well, pump, motor and irrigation system does not include a guarantee that the equipment will not break down during a period when water is critically needed for crop production. For these reasons, conservative values of production were selected for purposes of analyzing the economics of development.

Yields under irrigation were calculated by assuming that 60 percent of the increase in yield normally expected from full irrigation would on the average be attained. Yields will be less than those probable from a well-distributed, adequate irrigation supply. This is because there will be some irrigation equipment failures, and in the interests of economy some farmers will install systems somewhat under-designed. Also, there will be some cases where equipment is adequate, but due to poor judgment or other priorities, water application will be delayed beyond the desirable time or may be less than fully adequate in amount.

Estimates of hectare yields for the various crops grown under various production conditions are shown in Table 7. The first column of figures indicates expected yields if neither irrigation nor fertilization is carried out. The second column assumes irrigation but not fertilization, and the third assumes both are practiced.

Table 7. Yields for Selected Agricultural Products With and Without Irrigation

Crop	Unit	Without Irrigation*	With Irrigation**	With Irrigation and Fertilizer
Wheat[a]	qq/Ha	20	35	50
Cotton	qq/Ha	11	20	30
Sugar Cane	ton/Ha	35	85	120
Soya	qq/Ha	25 (19)#	48 (36)	60 (45)
Meat (forage)	AUM/Ha	9	30	60

* Reflects multi-year averages which incorporate years of low rainfall.
** Reflects averages with sufficient water or rainfall.

[a]Wheat is a winter crop which generally receives insufficient rainfall for production.

#Under double-cropping with cotton, soya yields are assumed to be 25 percent less than when grown alone.

Table 8 contains per hectare production costs, revenues and profits which accrue to various cropping alternatives. The five crops, cotton, soy beans, sugar cane, wheat and pasture, are evaluated first as single crops, where it is assumed that only one crop is grown per year. The final three rows of the table assume that wheat, soy beans, and green manure are double cropped with cotton.

Table 8. Production Costs, Revenues, and Profits to Water, Land, Family Labor and Management per Hectare in Cruzeiros

Crop	Irrigation or Fertilization			With Irrigation,* Without Fertilization			With Irrigation,* With Fertilization		
	Cost	Revenues	Profit	Cost	Revenues	Profit	Cost	Revenues	Profit
Cotton	1468	2035	567	1880	370	1820	2478	5550	3072
Soya	482	750	268	514	1440	926	612	1800	1188
Sugar Cane	1221	1575	354	2258	3825	1567	3182	5400	2218
Wheat	452	520	68	487	910	423	620	1300	680
Pasture (calves)	232	89	-143	532	710	178	1082	1768	686
Cotton-Wheat	1868	2555	687	2305	4610	2305	3036	6850	3814
Cotton-Soya	1840	2605	765	2277	4780	2503	3022	6900	3878
Cotton-Green Manure	1870	2035	165	2782	3700	1418	2880	5550	2670

*Does not include costs of irrigation development and operation.

The rotation recommended for the area is cotton and wheat the first year, cotton and soy beans the second, cotton and wheat again the third year, to be followed in the fourth year by cotton and then a green manure crop. The latter should be utilized at regular intervals to maintain favorable soil fertility and organic matter content. Sweet clover, or some tropical legume, would seem to be the best crops for the green manure.

Irrigation costs have not been included in Table 8. They are, however, netted out in the following Table 9. Per hectare net profits accruing to land, family labor and management are shown for two types of irrigation development---with and without fertilization, and without either irrigation or fertilization. Type 1 irrigation is sprinkling with water supplied from wells. Type 2 is gravity flow with water pumped from wells.

Several points are obvious from Table 9. Cotton is a very profitable crop, whether grown as a single crop or in combination with wheat, soy beans and even a green manure crop. Cotton is profitable without irrigation and fertilization but is even more profitable under irrigation and with fertilization.

Soy beans is a profitable crop if markets can be found for processed livestock feed and providing edible-oil processing plants are established.

Meat production from utilization of forage is unprofitable under the assumed conditions. One of the primary reasons is the high interest costs associated with financing the purchase of the animals.

Wheat production is profitable under assumed conditions except where no fertilizer is applied. As might be expected, it more than pays for itself if double cropped with cotton, although it is not as profitable as soy beans when combined with cotton. The major advantage of wheat is that presently no marketing problems exist, and none are foreseen in the future. In addition, wheat is readily adaptable to winter growing conditions.

Sugar cane revenues cover production costs, including fertilizer and irrigation. A cautionary note is warranted, however. Transportation costs are relatively important in cane production (in our examples more than 50 percent of total variable costs) and vary a great deal depending on the location of cane production relative to the location of the sugar factories. Where transportation costs are higher than average, profit ability estimates overstate true profits.

Table 9. Net Profit to Land, Family Labor and Management Under Various Irrigation Systems

Crop	Net Profit W/O Irrigation W/O Fertilizer	Net Profit With Irrigation			
		Without Fertilizer		With Fertilizer	
		Irrigation System		Irrigation System	
	Cr.	1 Sprinkler System	2 Gravity Irrig.	1 Sprinkler System	2 Gravity Irrig.
Cotton	566	1110	1146	2362	2396
Soya	268	438	456	700	718
Meat (pasture)	-143	1130	-1150	-621	-641
Wheat	68	-64	-47	193	210
Cane	354	314	332	966	984
Cotton-Wheat	688	1108	1160	2616	2668
Cotton-Soya	766	1306	1358	2680	2732
Cotton-Green Manure	164	164	298	1414	1550

INTERNAL RATES OF RETURN

The net profits reported in Table 9 are based on the present value system of calculation. All costs and returns are discounted at 15 percent interest and the net annual profits represent the return to irrigation investment. Another acceptable procedure for estimating rate of return on project investment is the Internal Rate of Return. This procedure has the advantage of expressing rates of return as a percentage which can be compared with the rate of interest charged in the capital market. Projects which generate internal rates of return which are above the borrowing rate of interest may be judged feasible, while the opposite is true for projects yielding internal rates of return below the borrowing rate. The internal rate of return is defined as that rate of interest which makes the present value of the project net benefit stream equal to the fixed investment costs.

Estimates of the internal rate of return were made for all single crop and double crop situations under the two irrigation systems analyzed. A summary is contained in Table 10.

Table 10. Internal Rates of Return for Selected Crop Under Various Irrigation Systems

Crop	Irrigation System	
	Sprinkler	Surface
	Percent Return	
Cotton	50	> 50
Soya	27	35
Meat (pasture)	< 1	< 1
Wheat	16	20
Sugar Cane	20	26
Cotton, Wheat	> 50	> 50
Cotton, Soya	> 50	> 50
Cotton, Green Manure	50	> 50

< Denotes less than.

> Denotes greater than.

Estimates of fixed investment costs in this particular analysis presented some conceptual problems. Wells were assumed to have a 15-year life, while well pumping plants had 10-year life expectations and laterals and main lines 8 years. All fixed costs were standardized at 15-year life expectancy in order to make them comparable with respect to time, which is required before internal rates of return can be calculated.

The following adjustments were made:

Investment cost with 10-year life	x 150% =	Investment cost 15-year equivalent
Investment cost with 8-year life	x 188% =	Investment cost 15-year equivalent

The effect of this adjustment was to purchase in terms of original investment an increase in the time lives of all equipment to 15 years.

Estimated internal rates of return (Table 10) equaled or exceeded the 15 percent interest-borrowing rate on all crops and irrigation systems, except pasture (meat). Cotton showed the highest rates of return, equaling or exceeding 50 percent in single or double crop situations.

Fixed costs used in the computations, annual benefits, annual costs, net benefits and internal rates of return are shown for the various crop and crop combinations in more detail in Table 11.

COMPARISON WITH SAO FRANCISCO BASIN

The Sao Francisco Basin comprises 7.5 percent of the Brazilian land area. The population is about 7,000,000 and the potentially arable land is about 3,000,000 hectares. The better soils areas in the Sao Francisco Basin appear to compare favorably with the better areas near Santa Cruz, Bolivia. Rainfall is somewhat less favorable in amount and distribution throughout much of the Sao Francisco Basin. Temperatures and humidities are similar, with Santa Cruz having somewhat lower winter temperatures (about 3°C lower during July) and probably somewhat higher mean relative humidities.

The area around Santa Cruz, Bolivia, has a better infrastructure for development with a more aggressive attitude towards development in irrigation. However, since much of the Sao Francisco Basin is dryer and

Table 11. Fixed Costs Used in the Computations, Annual Benefits, Annual Costs, Net Benefits and Internal Rates of Return

Irrigation System	Fixed Cost*	Annual Direct Benefits Due to Project Investment**	Annual Operating & Maintenance Cost	Annual Net Direct Benefits Due to Project Investment	Internal Rate of Return
		COTTON			
Sprinkler-Well	Cr 4470	Cr 2505	Cr 120	Cr 2385	> 50%
Surface-Well	3225	2505	190	2315	> 50%
		SOYA			
Sprinkler-Well	2965	920	95	825	27%
Surface-Well	2145	920	152	768	35%
		SUGAR CANE			
Sprinkler-Well	7428	1864	270	1594	20%
Surface-Well	5378	1864	435	1430	26%
		PASTURE (MEAT)			
Sprinkler-Well	7478	830	325	504	< 1.0%
Surface-Well	5378	830	525	304	< 1.0%
		WHEAT			
Sprinkler-Well	2965	612	95	517	16%
Surface-Well	2145	612	152	460	20%
		COTTON-WHEAT			
Sprinkler-Well	4470	3126	215	2911	> 50%
Surface-Well	3225	3126	342	2784	> 50%

*All fixed costs are standardized at a 15-year life equivalent. Project life for all benefits and costs is 15 years.

**Calculated as net returns with project minus net returns without project.

Table 11. (Continued)

Irrigation System	Fixed Cost	Annual Direct Benefits Due to Project Investment*	Annual Operation & Maintenance Cost	Annual Net Direct Benefits Due to Project Investment	Internal Rate of Return
		COTTON-SOYA			
Sprinkler-Well	Cr 4470	Cr 3112	Cr 215	Cr 2897	> 50%
Surface-Well	3225	3112	342	2770	> 50%
		COTTON-GREEN MANURE			
Sprinkler-Well	4470	2505	210	2295	50%
Surface-Well	3225	2505	302	2202	> 50%

*Calculated as net returns with project minus net returns without project.

soils seem comparable over a large area, it would appear that given time for the infrastructure to catch up, benefits should be comparable.

Although Souto Maior (2) describes the ground water potential of the Sao Francisco Basin in general terms, more specific information is needed prior to planning important irrigation development from ground water.

CONCLUSION

Because of the large capital requirements for major surface water irrigation projects and due to slowness in development to irrigation use and to slowness in attaining full project benefits, groundwater development should frequently be given major consideration as a means of promoting irrigation experience and initial infrastructure growth. In areas with limited ground water recharge it may be that the most economical use of ground water would be mining the resource over a period of perhaps 15 to 20 years. As reserves are depleted it frequently becomes economical to develop surface water supplies to replace ground water usage.

The economic analysis based upon the area near Santa Cruz, Bolivia appears to have considerable application to conditions in the semi-arid areas of Brazil characterized by favorable soil and groundwater conditions.

Additional investigation is required in order to define the groundwater potential for irrigation in Brazil.

Because ground water is not visable and its potential undefined, ground water is frequently a neglected natural resource. Basin-wide plans for development of many great river systems hardly mention the possibilities for utilization of ground water. The economic analysis included in this paper and a knowledge of existing developments clearly demonstrate the economic advantages of and the need for planned utilization. Under favorable conditions ground water development produces twin benefits---drainage and irrigation water.

APPENDIX-REFERENCES

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