

## ECONOMIC ASPECTS OF GROUNDWATER DEVELOPMENT AND USE

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## ABSTRACT

The choice of an optimal structure for a groundwater extraction system depends upon a large number of variables which are site specific, including such things as labor and capital costs, soil and slope conditions of lands to be irrigated, and the relative scarcity of water. These considerations notwithstanding, useful insights into the cost structure of groundwater use can be obtained by examining such costs within the context of conditions in the Southwestern United States, with emphasis given to relative costs and the tradeoffs between components of the groundwater extraction system. This is the end sought in this paper. Major components of the groundwater extraction system which are examined in this paper include water distribution systems, pumps, and alternative fuel types. Fixed and variable costs are described for each system, and conditions under which alternative extraction systems might be preferable are discussed. The primary trade-offs considered in these discussions are those between labor and capital intensive systems, and those between alternative distribution systems.

## 1 INTRODUCTION

This paper has as primary purpose the presentation of data which can provide a point of departure for discussions of the relative costs of alternative capital structures used in exploiting groundwater resources for irrigated agriculture. The major components of such systems are, of course, water application systems (furrow, drip, sprinklers, etc.), pumps, and canal/water delivery systems. These aspects of groundwater development and use will be discussed below.

One's choice of an optimal structure for a groundwater extraction system will, of course, depend upon a large number of variables which are site specific; examples in this regard include: the relative scarcity of water; depth to water table; the relative prices of fuel; crop mixes and, therefore, revenues; and soil/slope conditions of the lands to be irrigated. Obviously, we cannot cover in this short paper any and all conditions which might be encountered in irrigation areas throughout the world. Our discussions require some specific context, however, in which case our discussions of groundwater development are cast within the physical/economic environment found in the arid, southwest areas of the United States. While our data will then be of little direct use for applications relevant for differing agronomic and economic

conditions encountered in other parts of the world, our hope is that our focus on the importance of relative conditions as they relate to the optimal choice for groundwater extraction systems will be of more general use. In any case, the discussions should serve to set the stage for most productive parts of seminars: the interchange of ideas between professional researchers concerned with the developments and use of groundwater for irrigation purposes.

Our discussions are organized in the following fashion. In sections II through III, attention is focused primarily on agronomic and hydrological conditions which are relevant for choices related to water application and delivery systems. Brief comments concerning relative fuel costs and the resulting use of power systems in the United States are offered in section IV. Attention is narrowed to fixed and variable costs for alternative groundwater exploitation systems in section V.

## 2 WATER APPLICATION SYSTEMS FOR GROUNDWATER IRRIGATION

Various methods for applying water to crops with groundwater irrigation have been developed to meet the needs of different areas and crops being produced. Some of the conditions which determine the "best" type of a water application system for any given application include the following: the cost of water; slope of lands; soil depth and texture; type of crops cultivated; availability, quantity and quality of groundwater; depth to water tables (and, therefore, pumping costs); and the existence of problems such as salinity and poor drainage conditions. In what follows, and acknowledging the risks of over-generalization, we comment briefly on the relevance of many of the conditions listed above for the typical choice among eight different water delivery systems - the economic aspects of such choices are taken up below in section V. The eight systems to be sketched here are:

Border check-flood

Furrow

Sprinklers

    Hand move

    Wheel line

    Center pivot

    Drag hose

    Permanent set

Drip

A. Border Check-Flood Irrigation. Flood irrigation is typically found in areas with flat topography, inexpensive water, and large water deliveries. It is often the least efficient method in terms of use but is usually the lowest cost method for groundwater applications. One finds the use of border check irrigation in areas where virtually all types of crops are grown, particularly

in areas used for hay and pasture crops. Orchards and vineyards are often flooded because of ease of cultivation and is usually irrigated by contour checks.

In the most general terms, typical conditions which result in flood irrigation as an optimal choice for a water delivery system include the following:

- \* Soil grade of less than 3%;
- \* Crops such as alfalfa and pasture which require 0.2 - 0.3 meter grade per 100 meters of run;
- \* Water costs of \$ 0.008 per cubic meter or less;
- \* Water deliveries of 50-500 litres per second
- \* Relative abundant supplies of groundwater;

We note in passing that, in the United States, flood irrigation is the most commonly used water application system.

B. Furrow Irrigation. Furrow irrigation is a variation of flood irrigation where the water is confined to narrow furrows rather than wide border checks. Furrows may be either straight, zigzag (furrow blocking), or contour. Furrow irrigation is typically used for row crops, orchards, and vineyards. Annual field and vegetable crops which require 0.05 feet of grade per 100 meters because of germination problems, insect control, harvest, and rooting will typically use furrow irrigation methods. Some crops such as those harvested for seed are furrow irrigated because of weed control and harvesting requirements.

General conditions which lead to an optimal choice of furrow irrigation for groundwater application include the following:

- \* Slopes of less than 2%;
- \* Finely textured soils;
- \* Crops which are subject to drowning.
- \* Water costs and supply conditions similar to those required for border irrigation;

C. Sprinkler Systems. Sprinklers are generally used under conditions where flood or furrow irrigation cannot be used efficiently. Typically, such conditions include:

- \* Chemical and physical soil problems such as salinity or poor water penetration;
- \* Nontillage conditions;
- \* Slopes in excess of 3%;
- \* Limited, and therefore expensive, water supplies;
- \* Special conditions such as frost control, germination, leaching, or inadequate land grading.

In general, sprinklers require less labor than flood or furrow irrigation but the investment is higher and the 1.3-1.9 atmospheres of pressure needed to

operate the sprinklers plus friction loss in the pipes is equivalent to 30-45 meters in terms of pumping lift. Many types of sprinkler systems are in use. Some have special conditions under which they are used. Others are used under all conditions. A brief sketch of five alternative sprinkler systems is given in the following.

C 1. Hand move. These were the first sprinkler systems developed for irrigation and continue to be used for many situations. They are usable wherever sprinkler systems are applicable and can be used on most crops. Hand move systems may have either portable or buried main lines. Their major appeal lies in the lower capital costs required relative to other sprinkler systems (see section 5 below).

C 2. Wheel line. These systems were developed primarily to reduce the labor required for the hand move systems. Also, moving sprinklers is often an unpleasant task which many U.S. farmers would seem to prefer to avoid. Early wheel line systems were moved with a tractor or other external motive power. Most of the newer systems have a power unit mounted on the sprinkler line. These systems require a larger investment than the hand move systems but materially reduce the labor input. Thus, choice between hand move and wheel line sprinkler systems will often turn on the relative availability and costs of labor and capital - a tradeoff of obvious importance in developing countries.

C 3. Center pivot. A center pivot systems is essentially a variant of the mechanical wheel line system where instead of the entire line moving across the field, the line is fixed on one end and then pivots around that point. They have several disadvantages: the irrigation pattern is a circle and the corners of a square field are either not irrigated or must be irrigated by a hand move or other type of system, and the water distribution can be poorer than with other sprinkler systems.

Due to the fact that any pivot system cannot irrigate 100% of a field, their use has been limited until recently to areas of low land values. Recently, however, center pivots with a cornering system have been introduced in California. Although they are more expensive, the cornering device makes it possible to irrigate 96-97% of a field, thus expanding their use to higher valued land. Also, these systems apply water at a high rate, some soil cannot absorb it as fast as applied and runoff and possible erosion can be a problem.

C 4. Hose drag. This is another variation of the mechanical move systems but employs flexible hose rather than rigid pipe. The use of these systems has been confined largely to orchard drops. Experience has indicated a high labor requirement even with the mechanical moving feature.

C 5. Permanent set. The high investment cost (demonstrated below in section 5) of these systems has limited their use largely to orchards and vineyards (relatively high income crops) and where they can be used for frost

protection.

C 6. Drip Irrigation. This is the newest of all commercial water application systems used for groundwater, as well as surface water irrigation in California. It involves the frequent or daily application of water in the form of drops from small diameter tubes or mechanical devices called emitters to given areas. When correctly designed, the rate of application should penetrate the soil properly with minimum runoff. The emitters dissipate the pressure in the hose distribution network by means of either a small diameter orifice or a long flow path, and thus, reduce the water flow to drops of a few liters per hour. Most emission rates range from 2 to 8 litres per hour. The applied water moves through the soil by capillary flow. To achieve adequate wetting of the root zone, several emitters per plant may be required. The number of emitters depends on the size of the plant and the capillary conductivity of the soil to permit lateral water movement.

The volume of soil wetting around the plants is less with a drip system than is the case with other methods of irrigation. The wetted volume may vary from 5-10% of the soil volume around young trees to 40-60% of the soil area around mature trees or annual crops.

### 3 COMMENTS CONCERNING IRRIGATION EFFICIENCIES

Irrigation efficiency refers, of course, to the percent of the irrigation water which is used by crops after various losses occur. Water losses can occur throughout the irrigation complex and the total losses will vary from area to area depending on the source of water, the method of application, the type of soil, the crop being grown, the weather conditions, and the need for salt balance by leaching.

Irrigation efficiency is typically considered within two contexts: water conveyance efficiency and water application efficiency. Water conveyance efficiency refers to losses of water from its source to its destination (the plant). Conveyance efficiencies, which with unlined, dirt ditches, average between 60% and 80%, can be reduced via capital investments for concrete lined ditches or pipelines - - costs for which are discussed below in section 5. Conveyance efficiencies for concrete lined ditches and pipelines range from 80-90% and 90-95%, respectively, thus the potential economic returns from such investments.

Water application efficiency is measured by the ratio of water stored in the root zone of soils, which is then available to the plants, and the volume of water which is delivered to the field. Such water losses result largely from deep percolation below the root zone, but include surface runoff and evaporation from water and soil surfaces. Many waters contain soluble salts which must be leached through the plant root zone. Some deep percolation is a necessity to

maintain a favorable salt balance in the soil.

Common water application efficiencies vary from 40-90% depending upon water quality, type of irrigation, type of soil, length of irrigation run, slope, temperature, wind and other factors. While not as amenable to effects from investments as conveyance increased via capital expenditures. The most common example in this regard are investments for the purpose of land leveling.

#### 4 POWER COSTS

Most irrigated crop land using groundwater in the United States brought into production since the early 1970s has been developed in areas (the Pacific Northwest) where hydroelectricity is plentiful and relatively inexpensive, as well as in areas in the Midwest and Southeast where irrigation is used to supplement rainfall, where natural gas is not readily available and is relatively expensive, and where, therefore, electricity, diesel, and LP gas are extensively used.

Changes in the pattern of fuel uses in the U.S.'s irrigated agricultural sector to power pumps used for groundwater exploitation are shown in Table 1.

Table 1

Percentage of acreage irrigated by type of fuel and price of fuel in U.S., 1970 - 1985.

FUEL TYPE	1970	1975	1980	1985
Electricity				
% of IPV	47	59	58	60
Price \$/kWh	0.0212	0.0308	0.0442	.0717
Natural gas				
% of IPV	25	19	18	15
Price \$/Gcal	2.56	5.16	12.52	20.08
Diesel				
% of IPV	8	11	15	17
Price \$/litre	0,048	0,104	0,261	0,184
LP Gas				
% of IPV	13	7	6	5
Price \$/litre	0,037	0,081	0,164	0,192
Gasoline				
% of IPV	6	3	3	2
Price \$/litre	0,092	0,146	0,304	0,304

IPV = Irrigation Power Units

Sources: Type of fuel: "Annual Surveys of Irrigation Journal, 1971, 1976, 1981, 1986.

Prices of fuel: Statistical Abstract of the United States. U.S., Department of Commerce, Bureau of the Census, 102d (1981) and 107d (1986).

Thus, prior to the energy crisis in the mid-1970s, fossil fuels accounted for slightly over 50 percent of fuels powering groundwater irrigation units. Electricity accounted for the remaining 47 percent. However, by 1975 electricity became the dominating source accounting for about 60 percent of the fuel for powering irrigation power units in the U.S.. The major losers were natural gas and liquid petroleum (LP) gas, each dropping 6 percentage points between 1970 and 1975. The sources of fuels used for powering irrigation pumps remained fairly stable between 1975 and 1985 with electricity dominating, natural gas continuing to decline, and the use of diesel fuel increasing as more groundwater irrigation was developed in the Midwest and South.

The price of natural gas has increased almost 8 fold (784%) between 1970 and 1985 while the price of electricity has only increased 338 percent (Table 1). The price of diesel fuel increased over 5 fold during the 1970 - 1985 period, LP gas about 5 fold and gasoline only 3.3 fold.

Modern irrigation technologies such as sprinkler and drip irrigation have been playing an increasingly important role in agricultural production over the last thirty years. In 1980 about 5,260,000 hectares were irrigated with sprinkler systems, while about 283,000 hectares were irrigated with drip (Irrigation Journal, 1986). In 1985 about 9,470,000 hectares were irrigated with sprinkler systems, and about 625,000 hectares were irrigated with drip (Irrigation Journal, 1986). The diffusion of these irrigation technologies is far from over. They are constantly being improved and adjusted to use in a myriad of environments. Moreover, many times policies to encourage their use are considered as means to conserve water or energy. However, in spite of their wide use, there is a significant uncertainty and controversy regarding the exact merits of these technologies and their appropriate use (Caswell, 1982).

## 5 COST OF IRRIGATION SYSTEMS

In this section, attention is focused on the costs associated with alternative groundwater irrigation systems. Of primary concern in these discussions are alternatives related to the choice of pumps and pump drives, and water

application systems. Thus, in this section we focus on the economic dimensions of the system components discussed in agroeconomic and hydrologic terms above.

For expository purposes, our discussions of system costs are based on an assumed 400 hectare field with water supplied by a well having a 30 meter pumping lift. In the case of center pivot sprinklers, a 320 hectare field is assumed and, for center pivots with cornering systems, it is assumed that 380 hectares of a 400 hectares field is irrigated. We assume a medium textured soil, with six to eight irrigations per hectare and a maximum of 15 cm of water applied per irrigation.

For the purpose of calculating depreciation, the following, normally accepted years of life are used.

	Years of life
Wells	20-30
Pumps	20
Pipeline	20
Movable sprinklers	10
Permanent sprinklers	20
Hose drag	8
Drip systems	10
Aluminum tubing	10
Steel pipe, 14 gauge, dipped, buried	8
Steel pipe, 12 gauge, dipped, buried	15
Steel pipe, dipped, surface use	10
Steel pipe, galvanized, surface use	15
Asbestos-cement pipe	25
Plastic pipe	25
Concrete pipe	20
Electric motors	15-20
Pumps (50,000 hours)	10-20
Sprinkler heads - metal	7-8
- plastic	5
Hose	10
Emitters	10
Sprinkler pipe - permanent	10
- movable	5

Interest is calculated at 8% on the average value. Taxes and other overhead are calculated at 2% of the original cost. Labor is costed at \$6.00 per hour, which includes fringe benefits. Energy charges are based on those presented in Table 1 for 1985. Repairs are estimated at so much per volume of water or at a percent of the original cost, depending on our best sources of information.

In what follows, we begin in part A with a consideration of initial, capital investment costs associated with alternative types of pumping plants, as reflected by fuel sources, and with alternative water application systems. In part B our analysis is expanded to include total costs - fixed plus operating costs - as they relate to tradeoffs involved primarily in choices between total systems for groundwater exploitation, as such systems reflect water application technologies used.

A. Investment And Overhead Costs For Alternative Power And Water Application Systems. Investment costs for the various types of groundwater irrigation systems were derived from a variety of sources (Gilley and Supalla, 1983; Hawthorn, 1980; Reed, et al., no date; and Sullivan and Libbin, 1986). Electric pumping plants can be a bit more expensive than internal combustion engines which, in turn, are currently slightly more expensive than pumps which use natural or LP gas. In terms of combustion engines, those using gasoline are typically less expensive than diesel engines. Cost differences between the pumps (as contrasted with expected price differences between fuel costs) are usually not sufficiently great to be a primary determining factor in pump selection, however, and their relative prices vary considerably over time. Thus, for our purposes all pumps per se are costed at a constant price of \$610/hectare. Well development costs would also be invariant across pump/fuel types, and are costed at \$452/hectare.

Major variations in capital investment costs are then attributable to one's choice of a water distribution system. Referring to Table 2, investment costs per hectare are shown to be lowest for furrow irrigation at \$1242 while the per hectare investment costs for permanent set sprinkler are \$6036 per hectare (table 2). The large quantity of aluminum pipe and sprinkler heads account for over 80% of the investment costs in permanent set sprinklers. Drip irrigation has the second highest investment costs at \$4430 per hectare. A drip system accounts for over 80% of a farm's total investment costs. Center pivot sprinkler has the third highest per hectare investment costs at \$2828, followed closely by flood irrigation at \$2826, hose drag at \$2690, and center pivot

sprinkler with corner system at \$2619. In terms of sprinkler systems, hand move and wheel line systems are the least expensive and, as noted above, have the advantage of utilize larger proportions of available land than is the case with other sprinkler systems.

Looking next to overhead costs (Table 2), overhead costs per hectare are, as one would expect, closely correlated to the investment costs. Overhead costs consist of depreciation, interest on investment, taxes, and miscellaneous costs. Furrow irrigation is shown to have the lowest overhead costs (\$132 per hectare) while drip irrigation incurs the highest overhead costs (\$670 per hectare). These differences are primarily attributable to the shorter life of drip systems compared to other systems. Of course, all sprinkler systems have higher overhead costs than flood or furrow systems reflecting, again, differences in depreciation rates for the two classes of systems. Referring to sprinkler systems as a group, a wheel line sprinkler system has an investment cost of \$2352 and depreciation costs of \$183 while center pivot sprinkler systems have investment costs of \$2828 and depreciation of \$173, but the higher interest charges and taxes on the center pivot sprinkler more than offset the reduced depreciation.

Table 2. Summary of investment and overhead costs for alternative water application. Values in \$/hectare/year.

	Flood	Furrow	Center pivot	Center pivot with corner system	Wheel line sprinkler	Hand move sprinkler	Permanent set sprinkler	Hose drag	Drip
<b>Investment</b>									
Grading	904								
Well	452	452	452	452	452	452	452	452	452
Pump	338	338	588	588	610	610	610	610	361
Leveling		452							
Pipeline and valves	1132								
Sprinkler			1220	1470	1290	1018	4974	1628	
Drip system									3617
Other unused land			568	109					
<b>Total</b>	<b>2826</b>	<b>1242</b>	<b>2828</b>	<b>2619</b>	<b>2352</b>	<b>2080</b>	<b>6036</b>	<b>2690</b>	<b>4430</b>
<b>Overhead per hectare</b>									
Depreciation	96	40	173	200	183	156	301	257	403
Interest	148	67	173	116	94	84	242	109	178
Taxes, etc	57	25	67	54	47	42	121	54	89
<b>Total Overhead</b>	<b>301</b>	<b>132</b>	<b>413</b>	<b>370</b>	<b>324</b>	<b>282</b>	<b>664</b>	<b>420</b>	<b>670</b>

B. Total Costs For Alternative Groundwater Use Systems. Data concerning total system costs for groundwater exploitation systems with alternative water application systems are given for pumps using electricity, natural gas, diesel, LP gas, and gasoline as fuel sources. See Tables 3-7 and Figures 1-5 located at the end of the paper. For each fuel source, costs are shown to vary by techniques used for water application.

The general pattern of costs as they vary by water application technique are essentially the same for each fuel source - all costs are higher for the gasoline option given the higher price of gasoline - in which case they will be reviewed for only the case where electricity is used as a fuel source.

Total operating costs for farms which use electricity as a fuel source vary from \$277 per hectare where flood irrigation techniques are used for water application to \$674 in cases where furrow irrigation techniques are used (table 3 and figure 1). Furrow irrigation systems are most expensive in terms of operating costs due, primarily to the large expenditures required for land preparation (\$272 per hectare) and high labor costs (\$267 per hectare). The hose drag system has the second highest operating costs at \$561 per hectare reflecting high labor costs, pressurization requirements similar to sprinkler which then implies relatively high fuel costs, and relatively high repair costs.

Third in the ranking of operating costs is the hand move sprinkler systems followed by permanent set sprinkler systems at \$452 per hectare, drip and wheel line at \$398 and \$412, respectively. The lowest cost sprinkler system is the center pivot system. The total per hectare costs of pumping irrigation water using electricity as a source of fuel varied from a low of \$579 (flood irrigation) to a high of \$1116 per hectare for permanent set sprinkler systems; drip irrigation systems, with total costs of \$1067 per acre, have the second highest total costs (table 3). Referring to figures 1-5, the essentially bi-modal distribution of system costs across water application techniques is of particular interest. Permanent set sprinkler systems, and the drip system are "high cost" systems, the hose drag system has intermediate costs, and all other systems are effectively "low cost" on a per hectare basis. It is then appro-

Table 3. Summary of costs for various methods for groundwater irrigation using ELECTRICITY as a source of power. Values in \$/hectare/year.

	Flood	Furrow	Center pivot	Center pivot with corner system	Wheel line sprinkler	Hand move sprinkler	Permanent set sprinkler	Hose drag	Drip
Times irrigated	6	6	8	8	8	8	8	8	-
Water Applied (meters)	1,07	1,07	0,91	0,91	0,91	0,91	0,91	0,91	0,60
Investment per hectare	2,826	1,242	2,828	2,618	2,351	2,080	6,034	2,690	4,429
Overhead per hectare									
Depreciation	96	40	173	200	183	156	301	257	403
Interest	148	67	173	116	94	84	242	109	178
Taxes, etc	57	25	67	54	47	42	121	54	89
Total Overhead	301	131	412	371	324	282	664	420	669
Operating Costs per hectare									
Irrigation Preparation	45	272							
Labor	89	267	15	15	119	237	59	237	119
Fuel	128	128	235	235	237	237	237	237	131
Repairs	15	7	54	64	57	47	156	86	148
Total Operating	277	674	304	314	412	521	452	561	398
TOTAL COSTS PER HECTARE	579	805	716	684	736	803	1,116	981	1,067

appropriate to inquire as to the relative "benefits" attributable to these systems which are relevant for one's choice of a system - i.e., what are the attributes of the "high cost" systems which might justify their selection?. Setting aside agronomic and land characteristics which could very well dictate the preferability of one system over another (particularly between sprinkler systems and between sprinkler versus flood or furrow systems), the primary differences between the systems are, first, water use and, secondly, the use of labor. The "high cost" drip system, of course, uses the least amount of water and is therefore "worth" its higher cost in areas where water conservation is a critical consideration; relatively low labor costs also characterize the system, an important consideration in areas where labor costs are high - much less important, of course, in areas with excess labor supplies. Sprinkler systems will also yield water conservation "benefits" (relative to flood and furrow techniques) and, for the center pivot systems, dramatically reduce labor costs. In applications characterized by high unemployment, the more capital intensive methods may be difficult to justify, making flood and furrow techniques preferable, so long as limited water supplies are not a critical consideration. With unemployment and limited groundwater supplies, resulting tradeoffs between water-labor saving sprinkler techniques and labor-water intensive flood and furrow techniques are then obvious.

Data in Tables 3-7 are summarized in Table 8 at the end of the text. These data allow for an examination of system costs across fuel types used for pumps as well as across water application systems. From these data one sees that the total cost for operating selective irrigation systems was the highest for gasoline and lowest for electricity. Natural gas provided the second lowest total cost of the five fuels evaluated, diesel fuel third, and LP gas fourth. Flood irrigation provided the least cost method of irrigation across all fuel types varying from \$578 per hectare for electricity to \$770 per hectare for gasoline. Permanent set sprinler systems were the most expensive irrigation method across all fuel types varying from \$1117 per hectare to \$1470 per hectare for gasoline. Drip irrigation had the second highest total costs due to the high cost of gasoline. Hose drag had the third highest total costs for all fuels except gasoline.

The center pivot sprinkler irrigation systems had the second and third lowest total costs for all fuels except gasoline, where the furrow irrigation system had the second lowest total costs because of the high costs of fuels. The sprinkler systems required additional fuel to pressurize the system and with the high cost of gasoline, it pushed the costs of fuel to \$590 per hectare.

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Table 4. Summary of costs for various methods for groundwater irrigation using NATURAL GAS as fuel. Values in \$/hectare/year.

	Flood	Furrow	Center pivot	Center pivot with corner system	Wheel line sprinkler	Hand move set sprinkler	Permanent set sprinkler	Hose drag	Drip
Times irrigated	6	6	8	8	8	8	8	8	-
Water Applied (meters)	1,07	1,07	0,91	0,91	0,91	0,91	0,91	0,91	0,61
Investment per ha	2,826	1,242	2,828	2,618	2,351	2,080	6,034	2,690	4,429
Overhead per hectare									
Depreciation	96	40	173	200	183	156	301	257	403
Interest	148	67	173	116	94	84	242	109	178
Taxes, etc	57	25	67	54	47	42	121	54	89
Total Overhead	301	131	412	371	324	282	664	420	669
Operating Costs per ha									
Irrigation Preparation	45	272							
Labor	89	267	15	15	119	237	59	237	119
Fuel	141	259	259	259	259	259	259	259	146
Repairs	15	7	54	64	57	47	156	86	148
Total Operating	290	805	329	338	435	543	474	583	412
<b>TOTAL COSTS PER HECTARE</b>	<b>591</b>	<b>936</b>	<b>741</b>	<b>709</b>	<b>758</b>	<b>825</b>	<b>1,139</b>	<b>1,003</b>	<b>1,082</b>

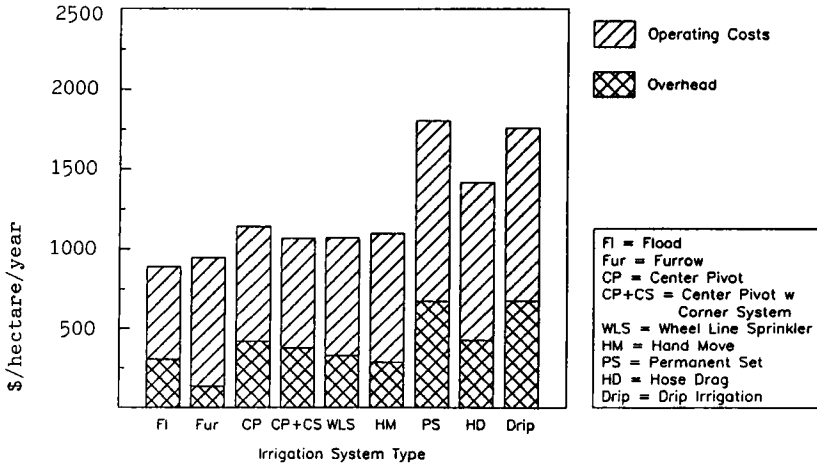


FIGURE 1. Cost of pumping irrigation water using electricity by type of irrigation system.

Table 5. Summary of costs for various methods for groundwater irrigation using DIESEL FUEL as fuel. Values in \$/hectare/year.

	Flood	Furrow	Center pivot	Center pivot with corner system	Wheel line sprinkler	Hand move set sprinkler	Permanent set sprinkler	Hose drag	Drip
Times irrigated	6	6	8	8	8	8	8	8	-
Water Applied (meters)	1,07	1,07	0,91	0,91	0,91	0,91	0,91	0,91	0,61
Investment per ha	2,826	1,242	2,828	2,618	2,351	2,080	6,034	2,690	4,429
Overhead per hectare									
Depreciation	96	40	173	200	183	156	301	257	403
Interest	148	67	173	116	94	84	242	109	178
Taxes, etc	57	25	67	54	47	42	121	54	89
Total Overhead	301	131	412	371	324	282	664	420	669
Operating Costs per ha									
Irrigation Preparation	45	272							
Labor	89	267	15	15	119	237	59	237	119
Fuel	168	168	311	311	311	311	311	311	173
Repairs	15	7	54	64	57	47	156	86	148
Total Operating	317	714	380	390	487	595	526	635	440
TOTAL COSTS PER HECTARE	618	845	793	761	810	877	1,191	1,055	1,109

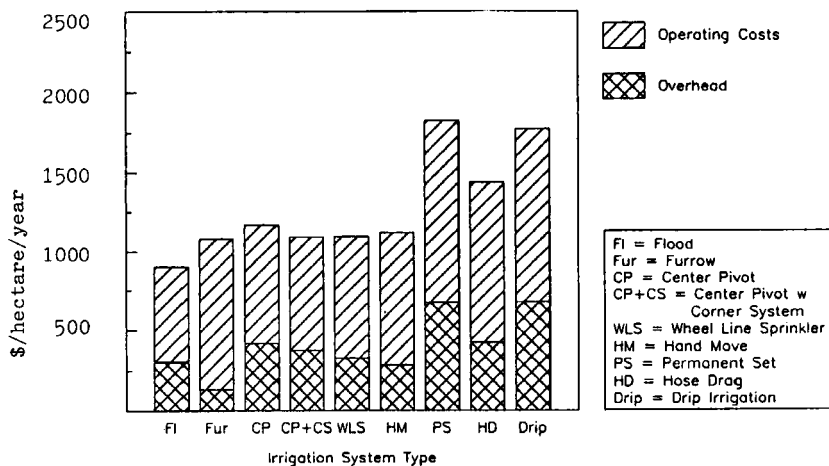


FIGURE 2. Cost of pumping irrigation water using Natural Gas by type of irrigation system.

Table 6. Summary of per hectare costs for various methods for groundwater irrigation using LP GAS as fuel. Values in \$/hectare/year.

	Flood	Furrow	Center pivot	Center pivot with corner system	Wheel line sprinkler	Hand move set sprinkler	Permanent set sprinkler	Hose drag	Drip
Times irrigated	6	6	8	8	8	8	8	8	-
Water Applied (meters)	1,07	1,07	0,91	0,91	0,91	0,91	0,91	0,91	0,61
Investment per ha	2,826	1,242	2,828	2,618	2,351	2,080	6,034	2,690	4,429
Overhead per hectare									
Depreciation	96	40	173	200	183	156	301	257	403
Interest	148	67	173	116	94	84	242	109	178
Taxes, etc	57	25	67	54	47	42	121	54	89
Total Overhead	301	131	412	371	324	282	664	420	669
Operating Costs per ha									
Irrigation Preparation	45	272							
Labor	89	267	15	15	119	237	59	237	119
Fuel	203	203	373	375	375	375	375	375	207
Repairs	15	7	54	64	57	47	156	86	148
Total Operating	361	748	442	454	551	659	590	699	474
<b>TOTAL COSTS PER HECTARE</b>	<b>653</b>	<b>879</b>	<b>855</b>	<b>825</b>	<b>874</b>	<b>941</b>	<b>1,255</b>	<b>1,119</b>	<b>1,144</b>

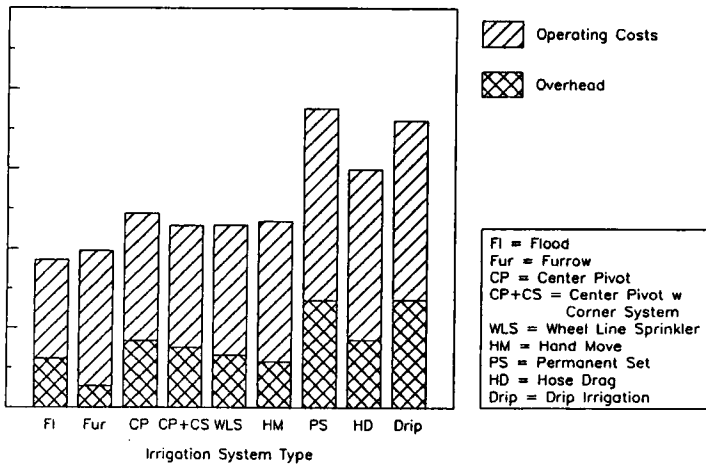


FIGURE 3. Cost of pumping irrigation water using Diesel Fuel by type of irrigation system.

Table 7. Summary of costs for various methods for groundwater irrigation using GASOLINE as fuel. Values in \$/hectare/year.

	Flood	Furrow	Center pivot	Center pivot with corner system	Wheel line sprinkler	Hand move sprinkler	Permanent set sprinkler	Hose drag	Drip
Times irrigated	6	6	8	8	8	8	8	8	-
Water Applied (meters)	1,07	1,07	0,91	0,91	0,91	0,91	0,91	0,91	0,61
Investment per ha	2,826	1,242	2,828	2,618	2,351	2,080	6,034	2,690	4,429
Overhead per hectare									
Depreciation	96	40	173	200	183	156	301	257	403
Interest	148	67	173	116	94	84	242	109	178
Taxes, etc	57	25	67	54	47	42	121	54	89
Total Overhead	301	131	412	371	324	282	664	420	669
Operating Costs per ha									
Irrigation Preparation	45	272							
Labor	89	267	15	15	119	237	59	237	119
Fuel	321	321	590	590	590	590	590	590	326
Repairs	15	7	54	64	57	47	156	86	148
Total Operating	470	867	659	669	766	874	805	914	593
TOTAL COSTS PER HECTARE	771	998	1,072	1,040	1,089	1,156	1,470	1,334	1,262

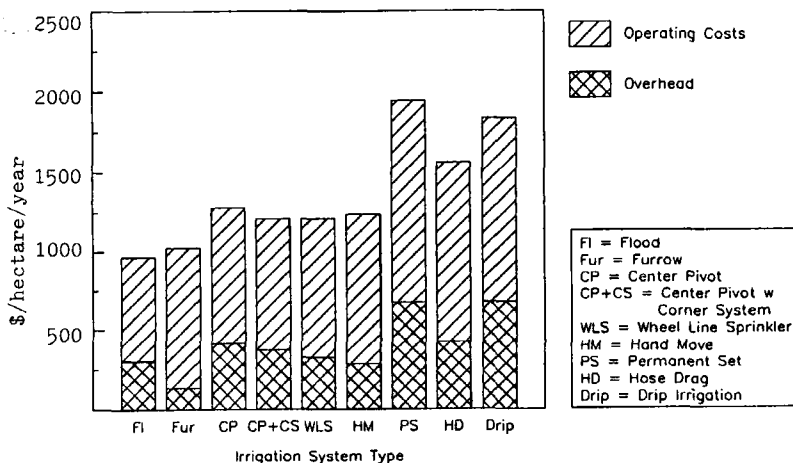


FIGURE 4. Cost of pumping irrigation water using LP Gas by type of irrigation system.

Table 8. Summary of costs for various methods for groundwater irrigation systems by source fuel. Values in \$/hectare/year.

	Flood	Furrow	Center pivot	Center pivot with corner system	Wheel line sprinkler	Hand move sprinkler	Permanent set sprinkler	Hose drag	Drip
Times irrigated	6	6	8	8	8	8	8	8	-
Investment per ha	2,826	1,242	2,828	2,618	2,351	2,080	6,034	2,690	4,429
Total Overhead	301	131	412	371	324	282	664	420	669
<b>ELECTRICITY</b>									
Operating Costs per ha									
Labor	89	267	15	15	119	237	59	237	119
Fuel	128	128	235	235	237	237	237	237	131
Other operating costs	59	279	54	64	57	47	156	86	148
Total Operating	277	674	304	314	412	521	452	561	398
TOTAL COSTS PER HA	578	805	716	684	736	803	1,116	981	1,067
<b>NATURAL GAS</b>									
Operating Costs per ha									
Labor	89	267	15	15	119	237	59	237	119
Fuel	141	259	259	259	259	259	259	259	146
Other operating costs	59	279	54	64	57	47	156	86	148
Total Operating	289	805	329	338	435	543	474	583	412
TOTAL COSTS PER HECTARE	590	936	741	709	758	825	1,139	1,003	1,082

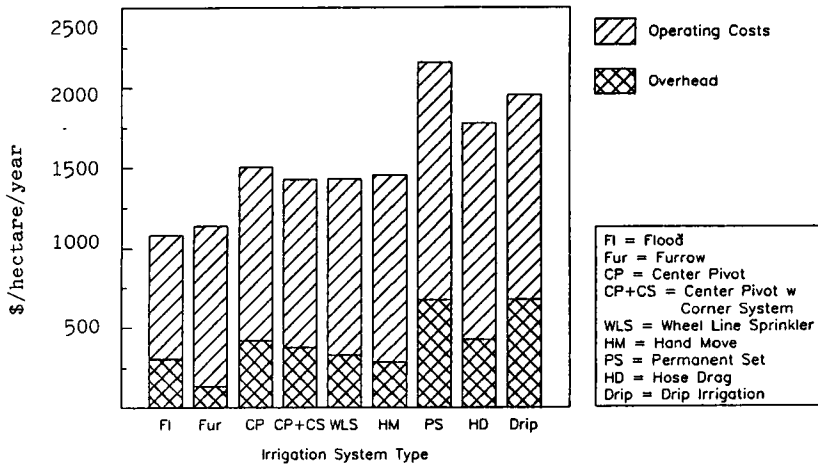


FIGURE 5. Cost of pumping irrigation water using gasoline by type of irrigation system.