AN ENGINEERING ECONOMIC ANALYSIS OF ARTIFICIAL RECHARGE IN A CONJUNCTIVE IRRIGATION PLAN IN THE COLUMBIA BASIN PROJECT, WASHINGTON

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METRIC (SI) CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4047.	square meter (m^2)
acre-foot (acre-ft)	1233.	cubic meter (m^3)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2d)
pound-force per square inch (lbf/in^2; psi)	6.895	kilopascal (kPa)

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ABSTRACT

An appraisal-level engineering economic cost analysis is performed for two primary types of irrigation systems in a part of the Columbia Basin Project. The first of these is a surface-water irrigation system in which farm units are supplied water via canals and laterals branching from a main-trunk canal. The second system is a plan in which surface water is brought to recharge wells and delivered to the farm units utilizing the transmissive properties of the aquifer and subsequent pumping. This recharge-irrigation system is further subdivided into two recharge-delivery schedules and two pumping-design options.

Based on the results of this study it was found that only at about today's electric power rate ($0.004 per kilowatt-hour in 1979) is an artificial-recharge irrigation scheme a potentially viable alternative to a surface-distributed irrigation system, provided yields of individual wells are at least 2,400 gallons per minute. However, as electric rates increase, this viability decreases until, at only three times the present rate, the recharge scheme becomes uneconomical.

INTRODUCTION

Artificial recharge of aquifers has been implemented in many places as a means of augmenting or replenishing water supplies for municipal and agricultural purposes (Brown and others, 1978; Price and others, 1962). The success or failure of such ventures in terms of cost savings over alternative means of accomplishing the same goals is dependent in part on the physical properties of the aquifers and in part on the difficulty of implementing the recharge schemes. If the aquifer's storage and transmissive characteristics are sufficiently favorable, high costs of surface-reservoir facilities can be avoided--both physical costs and environmental costs.

The supply aspect of water management, however, is not the only argument for a ground-water recharge study. An aquifer with adequate transmissive properties can potentially eliminate many of the distributional costs of delivering water to demand points via canals and conduits. These savings will be countered by the costs of recharge facilities and the costs of recovering the water through wells and pumping stations. These costs depend on such factors as the depth to the aquifer to be recharged, the pumping lift, and the quantity of the water considered. Therefore, the determination of the feasibility of a recharge system in terms of cost savings over alternative water-distribution systems needs to be done not only on a site-specific basis, but also on a project-specific basis.

The area selected to study the feasibility of artificial recharge is in the southern part of the Columbia Basin Project, where development of irrigable land is currently in the planning stages (fig. 1). The present plan is to import water from Roosevelt Lake to irrigation blocks via an extension of the East Low Canal (fig. 1) and to apportion the water to the farm units using a lateral distribution system (U.S. Bureau of Reclamation, 1975). An artificial-recharge-system alternative would, using the same water source and the extension of the East Low Canal area, divert water from the lateral system and deliver it to recharge facilities. The transmissive and storage properties of the aquifer would then be utilized to convey the water to the individual agricultural sections to be pumped for irrigation at the appropriate time. The deep basalt aquifer would be used to obtain ground water for irrigation in this area. From a project perspective, the economic tradeoffs between alternatives would be the savings from a reduced surface-conveyance system versus the costs of well construction, recharge facilities, and, most importantly, additional energy needs for pumping.

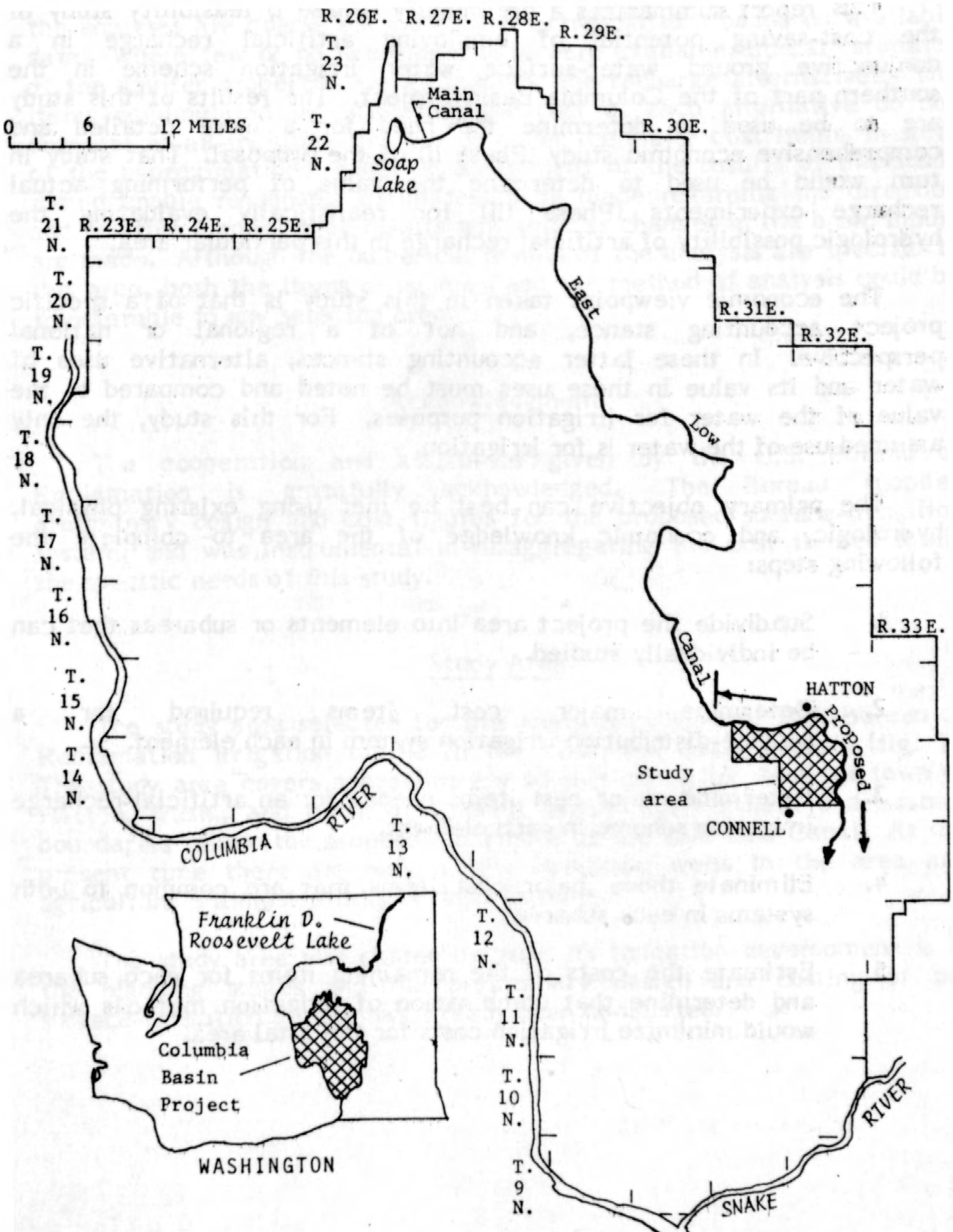

FIGURE 1.--Location of project area.

Purpose and Scope

This report summarizes a preliminary (Phase I) feasibility study of the cost-saving potential of employing artificial recharge in a conjunctive ground water-surface water irrigation scheme in the southern part of the Columbia Basin Project. The results of this study are to be used to determine the need for a more detailed and comprehensive economic study (Phase II) of the proposal. That study in turn would be used to determine the value of performing actual recharge experiments (Phase III) for realistically evaluating the hydrologic possibility of artificial recharge in this particular area.

The economic viewpoint taken in this study is that of a specific project accounting stance, and not of a regional or national perspective. In these latter accounting stances, alternative uses of water and its value in these uses must be noted and compared to the value of the water for irrigation purposes. For this study, the only assumed use of the water is for irrigation.

The primary objective can best be met using existing physical, hydrologic, and economic knowledge of the area to complete the following steps:

1. Subdivide the project area into elements or subareas that can be individually studied.

2. Determine major cost items required for a surface-distribution-irrigation system in each element.

3. Determine major cost items needed for an artificial-recharge-irrigation scheme in each element.

4. Eliminate those major cost items that are common to both systems in each subarea.

5. Estimate the costs of the remaining items for each subarea and determine that combination of irrigation methods which would minimize irrigation costs for the total area.

Because this report summarizes a preliminary study, all inputs into the analyses are coarse estimates and extrapolations based on available data. Where few or no hydrologic data were available, liberal estimates of the aquifer properties were made for the recharge alternatives. The items accumulated in estimating the cost of each alternative do not compose an all-inclusive list, but do cover the major cost items. In spite of the approximations made, an assessment of the results of this study should enable reasonable estimates to be made regarding the direction and relative amount that results will shift as changes in the basic inputs are made. Although the numerical results of the analysis are specific to this area, both the items considered and the method of analysis could be transferable to any selected area.

Acknowledgment

The cooperation and assistance given by the U.S. Bureau of Reclamation is gratefully acknowledged. The Bureau supplied preliminary design and cost figures for the proposed surface-irrigation system, and was instrumental in disaggregating the cost figures to fit the specific needs of this study.

Study Area

The study area selected for this analysis consists of U.S. Bureau of Reclamation irrigation blocks in the Columbia Basin Project (fig. 1). The study area covers approximately 45 mi^2 and is south of the town of Hatton, Wash., and north of Connell, Wash. Its northern and eastern boundaries follow the proposed extension of the East Low Canal. At the present time there are only a few irrigation wells in the area and agriculture is almost totally dryland farming.

The study area was chosen because its irrigation development is in the planning stages and the preliminary design and costing of the surface-irrigation system has already been completed.

DEFINITION OF ALTERNATIVES

In the study, the authors proposed five alternative irrigation schemes from which any combination will be a viable method for irrigation in the study area: (1) a total surface-water-distribution system; (2) a ground-water recharge and irrigation system in which recharge water would be delivered only during a 180-day-growing season, and in which ground water would be pumped from wells to supply single farm units (each 160 acres) of land; (3) a ground-water recharge and irrigation system in which recharge water would be delivered over a 270-day span (45 days on both sides of the growing season), and ground water pumped from wells servicing 160 acres; (4) a ground-water recharge and irrigation system in which water would be delivered only during the 180-day-growing season, and the ground-water pumped from a configuration of wells capable of servicing 320, 480, or 640 acres; and (5) a ground-water recharge and irrigation system in which water would be delivered over a 270-day span and the well system designed as in alternative (4). The reasons for dividing the extra 90 days of recharge on both sides of the growing season in alternatives (3) and (5) arise from several considerations. If the recharge begins a full 90 days prior to the growing season, there may be a large loss of recharge water out of the study area through lateral movement in the aquifer before pumping can begin. Recharging during the full 90 days after the growing season would cause greater drawdowns during pumping, because there could be no pre-growing season recharge and a greater loss of water would occur the next growing season. A final consideration is potential ice and cold-weather problems by beginning recharge too soon in the spring or finishing too late in the fall.

As the crop consumptive use and, therefore, farm delivery rate is expected to be approximately 4 acre-ft per acre (U.S. Bureau of Reclamation, 1975), alternatives (2) and (3) required pumping wells of approximately 1,200 gal/min capacity which would serve a 160-acre farm unit. The pumping strategies used in alternatives (4) and (5) required wells capable of servicing either 320, 480, or 640 acres. The wells and pumps needed for this plan would be 2, 3, or 4 times the above capacity.

For all alternatives, the ultimate source of water would be Roosevelt Lake via the East Low Canal. The amount delivered to the recharge wells would be equal to the amount that would have been delivered to the irrigation units in the surface irrigation scheme. The amount of recharge water 'lost' for later pumping because of ground water moving away from the study area was not considered to affect the results significantly. It was assumed that the same amount of water would be pumped from the aquifer as would be recharged to it. This assumption was made so that the analysis could be confined to a cost comparison of an equal amount of water applied for all alternatives.

PROCEDURAL-DESIGN CONSIDERATIONS

Because the purpose of this study is to estimate the potential for artificial recharge as part of a conjunctive irrigation scheme, the project area was divided into five subareas for analyses. After a cost analysis was made on each subarea to determine the alternative irrigation-system costs, the least-cost irrigation strategy for the total area was determined by finding a minimum-cost irrigation mix among the subareas.

The depth to the aquifer, based on existing irrigation wells in the project area, dictated that the only feasible recharge method is through injection wells. The number of recharge wells needed and their locations were adopted based on estimated aquifer properties, static-head elevation, and the designed canal system. The number of recharge wells was specified by the amount of water that could be transmitted into the aquifer by one recharge well under gravity feed. The recharge wells were placed as far upgradient as possible while an attempt was made to minimize canal length necessary to deliver water to the recharge wells. Requirements of complete aquifer recovery before the next irrigation season were included in the consideration of the placement of the recharge wells. The design and cost of canals under existing plans were used for the delivery canals. The amount of water recharged also defined the land area that could be serviced by one recharge well. As it would be difficult to apportion recharge-facility costs across subarea boundaries, the subareas were delineated according to recharge-facility location. Figure 2 illustrates the five subareas, designated A through E, and their recharge facility locations. The numbers and types of wells for each subarea and for each pumping scheme are given in table 1. For all irrigation options using ground water, it was assumed that farm units intersected by or adjacent to a recharge lateral or main canal could be most economically irrigated directly from turnouts off the lateral. This included the farm unit containing the recharge facility.

COST CONSIDERATIONS FOR ALTERNATIVES

A cost comparison between the surface-water irrigation system and the ground-water irrigation systems illustrates the counterbalancing of higher initial dollar outlays for surface irrigation against the greater operation costs in a ground-water system. In the comparison between recharge systems, the larger capital cost of the 180-day recharge option is countered with the higher operation cost of the 270-day recharge option. And finally, the ground-water system with the 1,200 gal/min pumps has a higher capital cost and a lower operating cost than does the system with the higher-yield pumps.

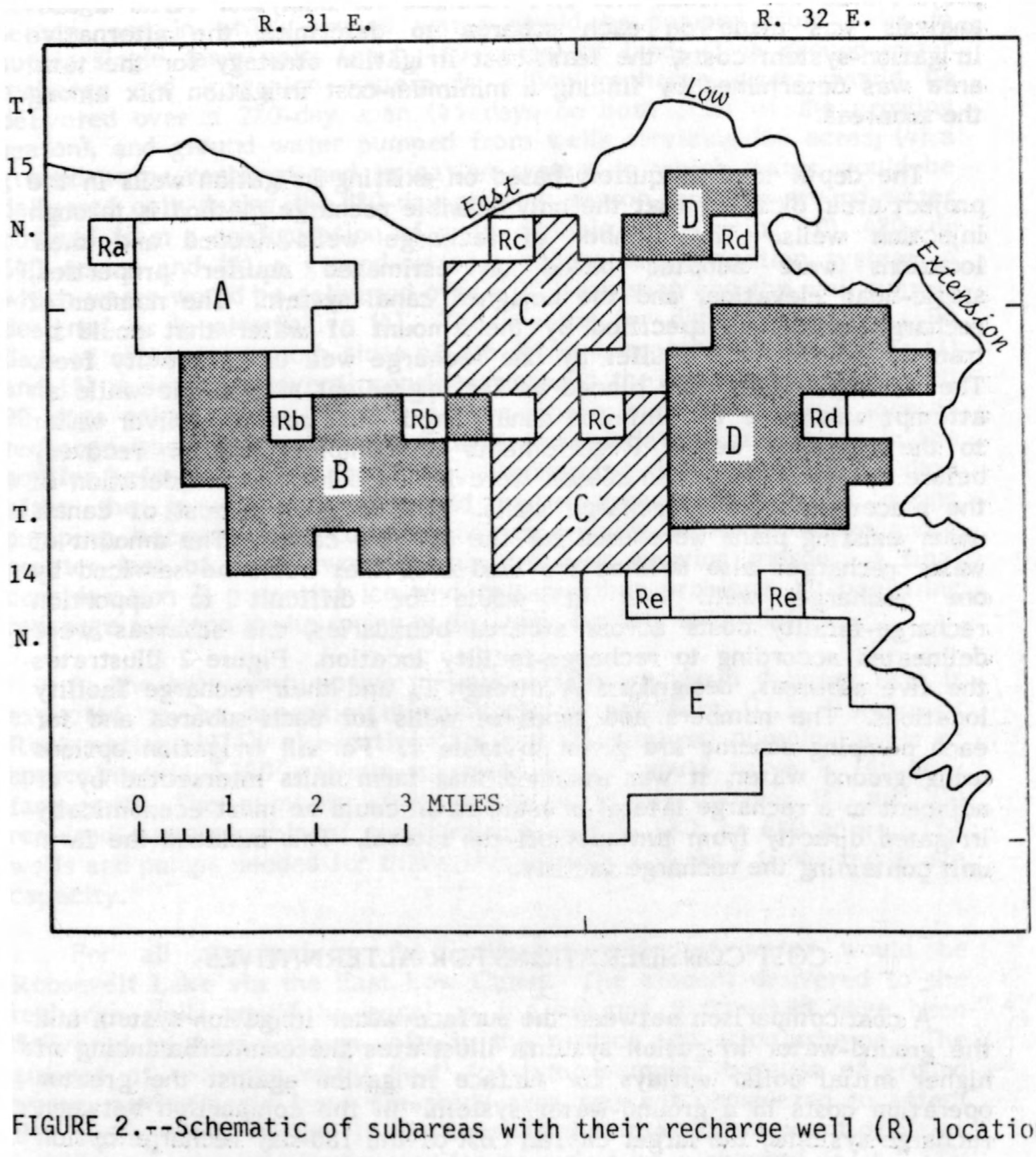

FIGURE 2.--Schematic of subareas with their recharge well (R) locations.

TABLE 1.--Summary of ground-water irrigation alternatives for 180-day and 270-day recharge systems

Subarea	No. of recharge wells	No. of 160-acre farm units served by ground water	Alternatives 2 and 3	Alternatives 4 and 5		
			No. of 1,200 gal/min pumps	No. of 2,400 gal/min pumps	No. of 3,600 gal/min pumps	No. of 4,800 ga;/min pumps
A	1	13	13	0	3	1
B	2	22	22	1	4	2
C	2	27	27	2	5	2
D	2	25	25	0	7	1
E	2	25	25	1	5	2

Although the discussion in the following paragraphs will include capital costs and operation and maintenance costs (OM), all costs were converted into uniform annual equivalents for analysis purposes by using a discount rate of 6 7/8 percent.

The capital costs considered for the surface-water irrigation system include the construction costs of the canals and laterals to deliver the water to the 160-acre farm units from the main supply canal, the installation of turnouts, relift pumps, and pumps needed to operate the irrigation sprinklers. Significant repeated costs include canal maintenance and pump operation costs.

Primary costs of the 180-day recharge system (alternatives 2 and 4) cover laterals to recharge wells from the main supply canal, well construction and development, construction of pumping stations, and recharge facilities. Major repeated costs are canal maintenance and pump operation.

The 270-day recharge scheme (alternatives 3 and 5) has pumping costs similar to the 180-day recharge system. The basic difference between the two is the reduced capital cost in the 270-day plan, because the smaller amount of water delivered per unit of time requires smaller canals. This saving will be somewhat offset, however, by increased operation costs at Roosevelt Lake and increased pump-operation cost during the growing season. Pumping lifts will also be greater because of the reduced aquifer recharge rates.

The planned surface-irrigation water deliveries are not constant during the growing season but would follow approximately the delivery distribution in table 2. (In addition to the values shown in table 2, 106.6 acre-ft per farm unit would be delivered prior to period 1 and following period 6 under the 270-day recharge system.) The canals for a surface-irrigation system must therefore be designed large enough to accommodate the largest 30-day water delivery. Because the pumping will satisfy the distributional allocation for crops in the ground-water systems, its recharging process and water delivery can be made at a constant rate. Thus, an irrigation system that used recharged ground water would require a smaller supply canal and laterals than would a surface-water irrigation system. This difference in cost is a savings to the recharge systems.

The costs for the surface-irrigation scheme in all subareas were estimated using unpublished U.S. Bureau of Reclamation preliminary figures. Costs associated with delivering water to the recharge facilities were also obtained from these same figures. Well-drilling costs, pump costs, and power costs for pumping in the ground-water alternatives were estimated using data supplies by W. R. Gillis and R. W. Dunford (written commun, 1980).

TABLE 2.--Water delivered per 160-acre farm unit during the 180-day growing season for surface water and both recharge systems (acre-ft)

System	30-Day Period Number					
	1	2	3	4	5	6
Surface irrigation system	51.0	115.0	160.0	154.0	102.0	58.0
180-day delivery recharge system	106.6	106.6	106.6	106.6	106.6	106.6
270-day delivery recharge system[a]	71.1	71.1	71.1	71.1	71.1	71.1

[a]106.6 acre-ft would be delivered prior to period 1 and after period 6.

PUMP-LIFT ESTIMATION

Estimation of pumping lifts realized in the recharge options was made using a two-dimensional, finite-difference ground-water-flow model (Trescott and others, 1976). The necessary hydrologic characteristics of the ground-water system were estimated using data available for the region. The transmissivity coefficient used in the model was 8,000 ft^2/d (pump-test data from wells in the region indicated a median value for transmissivity of 7,400 ft^2/d), and the storage coefficient was 0.005, which has been determined from other ground-water studies in adjacent area. Because of the sparcity of data, these values were held constant over the project area.

A uniform initial-head distribution was employed in the model. Six 30-day time steps were then used to simulate the irrigation season, with each well having an average pumping rate or recharge rate shown in table 1. Month-end drawdowns at each well for all four recharge cases were computed using the model. In the case of the 270-day recharge system, the six 30-day time steps were preceded by a 45-day time step having the uniform recharge rate as indicated by table 1.

In order to calculate pump lifts, the drawdowns at the wells computed from the model runs were averaged for the subarea and added to the average depth-to-water for each subarea (fig. 3) by use of the principle of superposition. A 140-ft, or 60-psi, head was added to the lift of each well to insure compatibility with surface irrigation in driving a sprinkler system. This defined each subarea's pumping lift for each 30-day time step. From these six pumping lifts, a maximum and an average value were obtained to determine maximum pump needs and maintenance costs, respectively. The energy costs for pumping were determined by summing the pumping costs for each 180 or 270-day time period. An example of maximum drawdowns for subarea B is given in figures 4 and 5 for both recharge options and both pumping schemes.

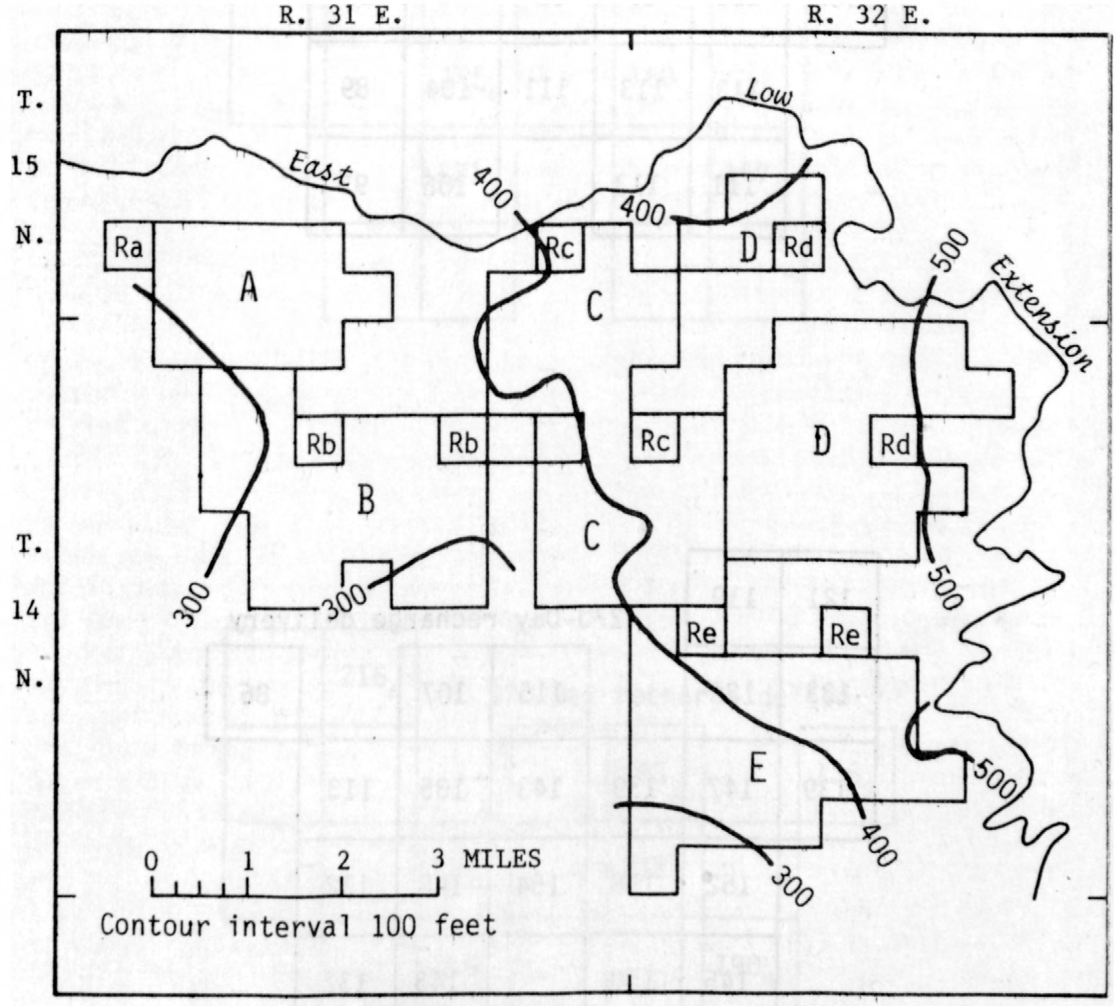

FIGURE 3.--Contours of depth to water, (from drillers' logs of wells drilled, 1965-78).

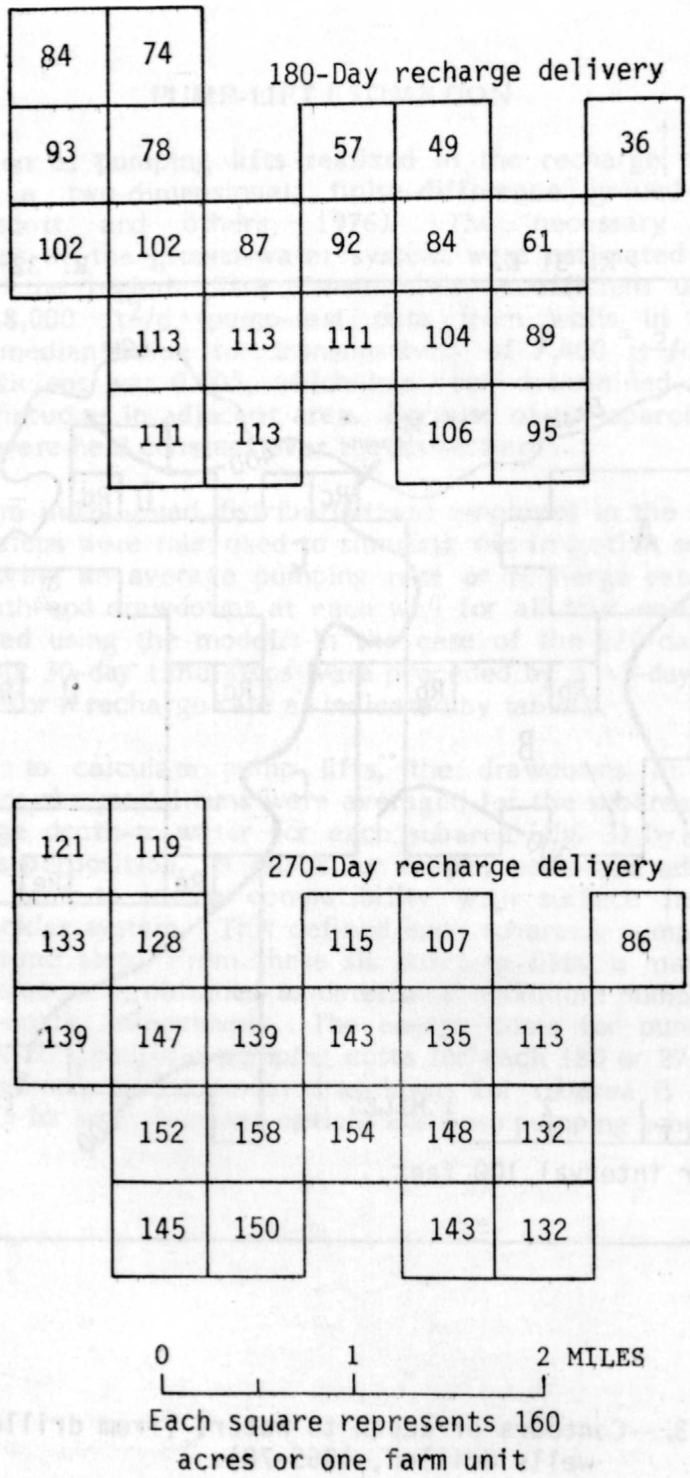

FIGURE 4.--Maximum drawdown, in feet, in each farm unit of Subarea B. All pumps = 1200 gal/min.

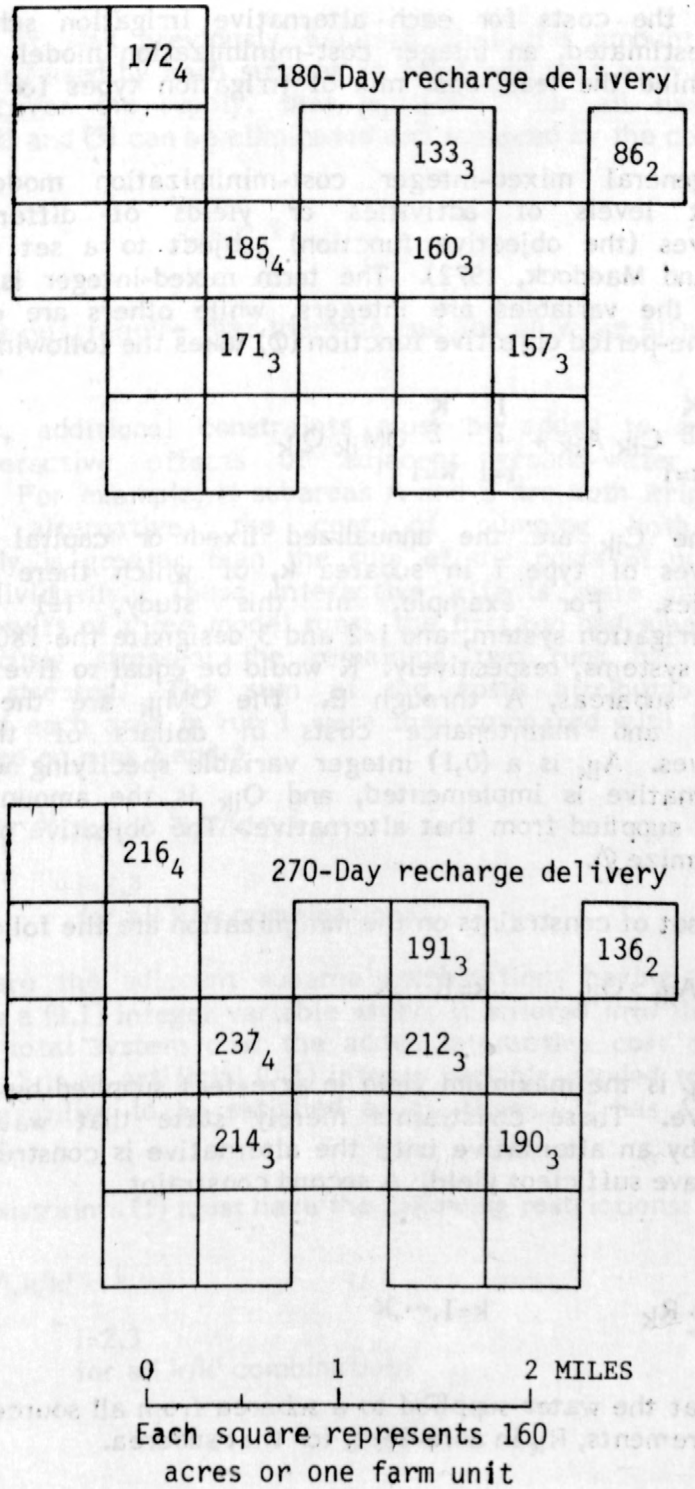

FIGURE 5.--Maximum drawdown, in feet, in farm units of Subarea B. High-capacity pumps (Subscript indicates farm units supplied by pump).

COST-MINIMIZATION MODEL

With the costs for each alternative irrigation scheme in each subarea estimated, an integer cost-minimization model was developed to determine the least-cost mix of irrigation types for the combined subareas.

A general mixed-integer cost-minimization model determines least-cost levels of activities or yields of different proposed alternatives (the objective function) subject to a set of constraints (Moody and Maddock, 1972). The term mixed-integer is used because some of the variables are integers, while others are continuous. A single-time-period objective function ($\emptyset$) takes the following form:

$$\emptyset = \sum_{i=1}^{I} \sum_{k=1}^{K} C_{ik} A_{ik} + \sum_{i=1}^{I} \sum_{k=1}^{K} OM_{ik} Q_{ik} \qquad (1)$$

where the C_{ik} are the annualized fixed or capital costs of the alternatives of type i in subarea k, of which there are I and K possibilities. For example, in this study, i=1 designates a surface-irrigation system, and i=2 and 3 designate the 180- and 270-day recharge systems, respectively. K would be equal to five because there are five subareas, A through E. The OM_{ik} are the total annual operation and maintenance costs in dollars of the respective alternatives. A_{ik} is a (0,1) integer variable specifying whether or not the alternative is implemented, and Q_{ik} is the amount of water in acre-feet supplied from that alternative. The objective of this analysis is to minimize $\emptyset$.

The set of constraints on the minimization are the following:

$$\sum_{i=1}^{I} Y_{ik} A_{ik} \geq Q_{ik} \qquad k=1,\cdots,K \qquad (2)$$

where Y_{ik} is the maximum yield in acre-feet supplied by the respective alternative. These constraints merely state that water cannot be supplied by an alternative until the alternative is constructed, and that it must have sufficient yield. A second constraint

$$\sum_{i=1}^{I} Q_{ik} \geq R_k \qquad k=1,\cdots,K \qquad (3)$$

states that the water supplied to a subarea from all sources must satisfy the requirements, R_k in acre-feet, for that subarea.

Because it was previously assumed that the amount of water supplied to and used by each subarea is fixed and that each alternative can singly cover the supply, that is, Q=R=Y for all subareas, the constraints (2) and (3) can be eliminated and replaced by the constraints

$$\sum_{i=1}^{I} A_{ik} = 1 \qquad k=1,\cdots,5 \tag{4}$$

which, simply put, require that there be one and only one alternative for each subarea.

However, additional constraints must be added to account for possible interactive effects of adjacent ground-water irrigation alternatives. For example, if subareas A and B are both irrigated using a recharge alternative, the cost of pumping both subareas simultaneously is greater than the sum of the costs of pumping the subareas individually. These interactive effects were obtained by comparing results of three model runs: the first run had subareas A and B simultaneously stressed; the remaining two runs had A and B individually stressed. The sum of the costs attributable to the drawdowns of each area in run 1 were then compared with the sum of the costs based on runs 2 and 3.

$$A_{i,k} + A_{i,k'} - M_{i,k/k'} + S_{i,k/k'} = 1 \tag{5}$$

$$i=2,3$$
for all k/k' combinations

where k/k' are the adjacent subarea combinations having interactive effects. M is a (0,1) integer variable which, if entered into the solution, adds to the total system cost the added interactive cost of the k/k' combination. S is an artificial (0,1) integer variable needed to allow the constraint flexibility to be satisfied at all times. It has a zero cost attached to it.

These constraints (5) must have the following restrictions:

$$M_{i,k/k'} + S_{i,k/k'} \leq 1 \tag{6}$$

$$i=2,3$$
for all k/k' combinations

For a triple interactive effect, that is, subareas k, k', k", the two following constraint sets must be added.

$$A_{i,k} + A_{i,k'} + A_{i,k''} - M'_{i,k/k'/k''} + 2S'_{i,k/k'/k''} + S''_{i,k/k'/k''} = 2 \qquad (7)$$

$$i=2,3$$
$$\text{for all } k/k'/k'' \text{ combinations}$$

and

$$M'_{i,k/k'/k''} + S'_{i,k/k'/k''} + S''_{i,k/k'/k''} \leq 1 \qquad (8)$$

$$i=2,3$$
$$\text{for all } k/k'/k''$$

Again, M' is a (0,1) integer variable that has a cost coefficient in the objective function correcting for the interaction costs of subareas k, k', and k" and a ground-water option as an alternative. S' and S" are (0,1) zero-cost artificial variables allowing constraints (7) to be satisfied at all times.

Constraints (5) through (8) allow the simulation of quadratic and cubic integer variables in an otherwise linear optimization scheme. The k/k' subarea combinations considered in this study were A/B, B/C, C/D, C/E, and D/E. The only triple combination considered was C/D/E. These choices were based on the geometrical pattern of the subareas in the total area as they related to the static-head gradient.

With the above constraints now defined, the objective function, O, becomes

$$\emptyset = \sum_{i=1}^{I} \sum_{k=1}^{K} C_{ik} A_{ik} + \sum_{i=2}^{3} \left(\sum_{k/k'} C'_{i,k/k'} M_{i,k/k'} + C''_{i,k/k'/k''} M'_{i,k/k'/k''} \right) \qquad (9)$$

when C' and C" are the respective coefficients to cover the interaction effects and C now includes both fixed and OM costs. Equation 9, together with constraint equations 4 through 8, comprise the cost-minimization model.

Because of practicality considerations, the solution scheme used solved the integer program comparing the surface-irrigation alternative with each of the four ground-water alternatives independently. This approximation eliminates the determination of the effects of the many possible interactions between recharge schemes. The solutions to the cost model were performed using the Mathematical Programming System - Extended (IBM, 1971).

RESULTS

The findings of this study do not reflect the total cost of the irrigation system in the project area, but only the comparative cost of the differences among the alternatives previously discussed. To obtain total system costs, those cost items that are common to all irrigation systems must be added to the comparative costs. These are essentially the main-trunk-canal costs and lateral costs off this main canal. However, the purpose of this study was not to assess the total project cost, but only to determine the types of irrigation scheme that would minimize system costs.

A total of eight cost comparisons was made. Their results are summarized in tables 3 through 6. No interaction costs were listed in tables 3 or 6 because they would only increase the costs of the ground-water systems that are already more expensive than the surface-water alternatives in all cases. To insure a common base of comparison, all costs were reduced to uniform annual payments based on a 100-year total project life with an interest rate of 6 7/8 percent (W. R. Gillis and R. W. Dunford, written commun, 1980).

The first recharge system contrasted with the surface-delivery system was the ground-water irrigation strategy using alternatives 2 and 3. The wells used in all recharge options in this report were assumed to be drilled to a depth of 1,000 feet. Based on figure 6, which illustrates the basalt well-depth requirements for the area to obtain the necessary yields, this is shown to be a conservative estimate for ground-water irrigation. Compared to both recharge delivery rates (table 3), the surface system was much less expensive in all subareas. This comparison was made using the existing electric power cost of $0.004 per kilowatt-hour (kWh). At higher costs for energy, the recharge systems would drop even further behind. The costs for these first recharge schemes were even more conservative because no recharge-facility costs were considered.

TABLE 3.--Annual comparative costs (in thousands of dollars) by type and subarea. (Comparisons 1 and 2: surface irrigation versus alternatives 2 and 3 (power costs = $0.004/kWh)

Subarea	Surface irrigation	Alternative 2 180-Day recharge	Alternative 3 270-Day recharge	Optimal irrigation type
A	110	170	167	SW
B	276	319	316	SW
C	205	378	380	SW
D	237	336	340	SW
E	292	335	322	SW

TABLE 4a.--Annual comparative costs (in thousands of dollars) by type and subarea. (Comparisons 3 and 4: surface irrigation versus alternatives 4 and 5 (power costs = $0.004/kWh)

Subarea	Surface irrigation	Alternative 4 180-Day recharge	Alternative 5 270-Day recharge	Optimal irrigation type
A	110	109	110	SW
B	276	226	221	GW
C	205	251	250	SW
D	237	217	217	GW
E	292	221	207	GW

TABLE 4b.--Annual interaction costs(1) (in thousands of dollars) for alternatives 4 and 5 in table 4a (power costs = $0.004/kWh)

Subarea combination	Alternative 4 180-day recharge	Alternative 5 270-day recharge
A-B	8	14
B-C	15	30
C-D	20	32
C-E	14	24
D-E	9	15
C-D-E	36	67

(1) Interaction costs must be added to comparative ground-water costs in the appropriate cases to get total annual relative costs.

TABLE 5a.--Annual comparative costs (in thousands of dollars) by type and subarea. (Comparison 5 and 6: surface irrigation versus alternatives 4 and 5 (power costs = $0.008/kWh)

Subarea	Surface irrigation	Alternative 4 180-Day recharge	Alternative 5 270-Day recharge	Optimal irrigation type
A	116	136	136	SW
B	286	265	264	GW
C	217	307	310	SW
D	249	275	278	SW
E	304	272	262	GW

TABLE 5b.--Annual interaction costs (in thousands of dollars) for alternatives 4 and 5 in table 5a (power costs = $0.008/kWh)

Subarea combination	Alternative 4 180-day recharge	Alternative 5 270-day recharge
A-B	10	18
B-C	16	34
C-D	22	39
C-E	15	28
D-E	9	19
C-D-E	38	83

TABLE 6.--Annual comparative costs (in thousands of dollars) by type and subarea. (Comparison 7 and 8: surface irrigation versus alternatives 4 and 5 (power cost = $0.012/kWh)

Subarea	Surface irrigation	Alternative 4 180-Day recharge	Alternative 5 270-Day recharge	Optimal irrigation type
A	122	161	163	SW
B	296	305	306	SW
C	229	363	370	SW
D	260	333	340	SW
E	315	323	317	SW

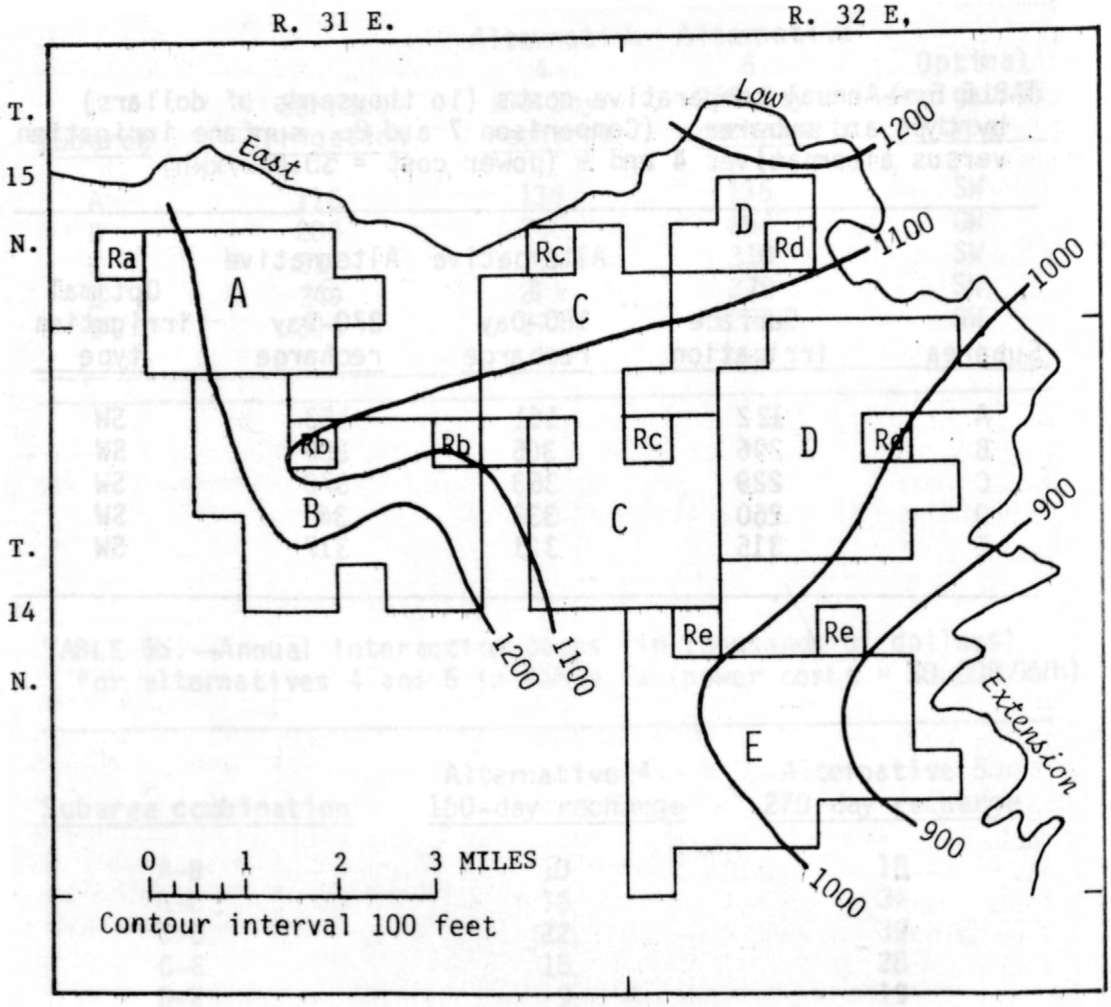

FIGURE 6.--Contours of equal well depth in area (from drillers' logs of wells drilled, 1965-78).

The remaining six cost comparisons contrasted the costs of the surface-irrigation system with each (180- and 270-day recharge delivery) of the alternatives 4 and 5. During the analysis, it was found that the cost per acre-foot of irrigation water applied was independent of well and pump size for these higher capacity units, and therefore the placement and required number of each of these larger units in the subareas was not a factor in the cost analysis.

These last six cost analyses compared surface irrigation to the 180-day and 270-day recharge systems for three electric power consumption rates: $0.004/kWh, $0.008/kWh, and $0.012/kWh. Tables 4-6 show the irrigation combinations for the study area for each power rate. Because recharge-facility cost estimates for such recharge-facility items as stilling basins and water-treatment facilities were not readily available, the only recharge-facility costs applied to the subareas were the costs of the estimated minimum-size recharge wells needed. This resulted in conservative estimates for ground-water-irrigation costs per subarea.

DISCUSSION AND RECOMMENDATIONS

Table 7 shows the projected electric rate schedule for irrigators in Franklin County, Washington, which is adjacent to the project area, through the year 2078 (W. R. Gillis and R. W. Dunford, written commun, 1980). If this rate schedule is converted to an average uniform annual rate for the next 100 years, a figure of $0.031/kWh is reached (for no real increase in rates after the year 2000, this value is approximately $0.015/kWh). According to table 6, all artificial-recharge strategies are found uneconomical at a rate less than half $0.031/kWh for all subareas. This outcome is reached in spite of the fact that very conservative recharge-facility costs were used.

A significant savings achieved by the artificial-recharge system over a surface-distribution irrigation system is attributable to the reduced main-supply-canal size. In addition, approximately 45 mi of open laterals would be eliminated by totally using recharge. If the area to be irrigated is located nearer to the supply of water, less savings are realized. Therefore, this would be a contributing factor to the diseconomies of any recharge program of this type, even at a lower power rate than $0.012/kWh.

TABLE 7.--Projected retail-demand electric rates* for Franklin County Irrigators, 1979-2079 (from Gillis and Dunford, 1980)

Year	Retail Rate ($/kWh)
1979	0.0040
1980-81	.0058
1982-83	.0066
1984-85	.0077
1986-90	.0092
1991-95	.0119
1996-2000	.0155
2000-78	2% annual increase

*Projected rates for 1979-2000 based on unpublished data provided by Bonneville Power Administration.

The economies of a large pumping-system irrigation network over a system of one pump per 160 acres are in the well and pumping-station construction costs. A well servicing 480 acres does not cost three times as much as one serving 160 acres. However, in power costs alone, the costs per acre-ft for the smaller capacity wells are slightly less than those of the larger wells because the lift is generally less. It should be noted that no additional distribution costs of the high-capacity wells over the smaller system were considered in this cost analysis. It is also interesting to notice the effects of the increasing power rates surpassing canal savings between the two recharge systems in tables 4 through 6, as indicated by the switching of irrigation schemes from ground water to surface water in subareas B, D, and E.

The scenario of this economic study could have been one of a declining-water-table in an existing ground-water irrigated area. An analysis such as in this study could be performed to determine if it were desirable to maintain irrigated agriculture in the area through water importation. For this case, the wells and pumping stations would already exist, thereby eliminating these capital costs. Rough approximations would show all recharge schemes to be economically attractive, from a project perspective, even for a three-fold power-rate increase over the present rate, and some still attractive for a six-fold increase, depending on the recharge facility costs. This rate, however, would still be less than the projected $0.031/kWh and also less than the projected rate with no real rate increase after the year 2000.

No quantitative sensitivity analyses on the hydrologic inputs were performed because of the computer costs involved in running the ground-water model and because power costs are clearly the primary factor. Qualitatively, however, it can be seen that as the transmissivity is reduced, the recharge alternatives become less attractive because of the increased need for recharge facilities and canals to deliver the water to these facilities, and pump lift increases, resulting in more cost to the system. As the transmissivity decreases, the recharge system approaches a surface-irrigation system. The converse of these arguments holds also as hydrogeologic conditions change in the opposite direction.

CONCLUSIONS

Based on the previous considerations and the system design, this study suggests that an artificial-recharge-irrigation operation is not an economical alternative to a surface-irrigation system in the study area. Study of systems utilizing shallower aquifers and different types of recharge may be worthwhile to pursue. A shallower aquifer would require less expensive wells and pumps and reduced electric power, and a water-spreading type of recharge might be possible. Under the conditions specified in this study, however, it appears that the added information gained from continuing into Phase II would not justify the costs needed to complete the study.

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