ECONOMICS OF REPLACING OPEN IRRIGATION DITCHES WITH GATED PIPE

by

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THIS IS AS RECEIVED FROM CUSTOMER.

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INTRODUCTION

In 1977, Kansas had 3.16 million acres of irrigated farm land according to Sloggett (1979). Of this total, 3.07 million acres were served from groundwater resources leaving only 90,000 acres irrigated by surface water resources. This compares with 1962, when there were a total of one million acres irrigated in Kansas. From 1974 to 1977 energy costs to pump the water increased from $570 million to more than $1 billion, yet the increased costs failed to slow the growth of pump irrigation. Of the 3.16 million acres irrigated in 1977, 2.27 million acres were irrigated by surface methods.

With diminishing groundwater supplies in the mid-western United States and rapidly increasing energy costs, the efficient use of water for irrigation is becoming more important every day. How well a given irrigation system performs with respect to water use efficiency depends on many factors, such as type of system, quality of design, competence and adequacy of labor, quality of management, and soil characteristics.

Irrigation supply ditches are one source of water losses in the great plains region. Large losses can occur in open ditches due to seepage and evaporation. Dickerson (1964) investigated losses from open ditches and found that seepage losses are much greater than evaporation losses. Open ditches are normally used in conjunction with siphon tubes for surface irrigation of borders or furrows. Seepage and evaporation can be eliminated by replacing the open ditch with pipe (usually gated aluminum or plastic).

PURPOSE

An ever-increasing need for water conservation in areas where water is needed for irrigation demands that water losses be minimized whenever possible. The facts that open ditches lose large amounts of water to seepage and evaporation and that these losses can be eliminated by replacing the open ditch with pipe suggest that an effort should be made to convince irrigators to switch to gated pipe. The purpose of this paper is to examine the economics of going to gated pipe and to present the results in a manner such that irrigators can understand and utilize them. This will be accomplished by looking at the cost of pumping wasted water (by using a breakeven energy cost equation) and seeing if the savings in pumping costs in a more efficient gated pipe system will pay for the pipe used to replace the open ditch. In the past this approach was not feasible because energy costs were low enough that the pumping cost for the wasted water was minimal as compared to the cost of gated pipe. A second approach will be to look at the possibility of replacing an open ditch system with gated pipe on the basis of potential productivity of the conserved water.

METHOD AND PROCEDURE

Cost of Water Loss Based on Pumping Costs

It is desired that any irrigator could plug in the characteristics of his individual irrigation system to this analysis and come up with a result which would tell him it is cost effective to change to gated pipe now or it is not cost effective to change now. In order for this to be possible many factors must be considered and explained clearly. The factors or variables are:

1) Static Water Level (H) in feet- This is the depth to the water surface in the well from ground level while the pump is not being operated.
2) Well Capacity (W_c) in gallons per minute- Output of the well when pumping.
3) Duration of Pumping per Year (T) in hours.
4) Length of Ditch to be Replaced with Pipe (L) in feet.
5) Energy to Power Conversion Factor (EP)- This varies with fuels and is given in terms of water horsepower hours (WHP-HR) per appropriate unit, see Table 1.
6) Cost of Pipe (P) in dollars per foot- This should be the price an individual farmer could purchase pipe for in his area.
7) Interest Rate (I) as a decimal.
8) Expected Life of Pipe (LF) in years.

Table 1. Energy to Power Conversion Factors for Various Fuels. From Nixon (1979).

Fuel	EP (WHP-HR)
Diesel	10.94/Gallon
Gasoline	8.66/Gallon
Propane	6.89/Gallon
Natural Gas	$66.70/1000ft.^3$
Electricity	0.885/Kilowatt-Hour

9) Specific Capacity of Well (S_c) in gallons per minute per foot of drawdown- Drawdown is the difference in elevation between the groundwater table and the water surface at the well when pumping. For example, if well capacity (W_c) is 1200 gallons per minute and drawdown is 60 feet, specific capacity (S_c) will be 1200 g.p.m./60 feet = 20 g.p.m./ft.

10) Additional Head Needed to Operate Pipe System (H_p) in feet- Pressure necessary for a typical surface gated pipe system is 10 pounds per square inch (psi) which when converted to feet is 23.1 feet of head. However, Dickerson (1964) states that "The time that water is in a ditch is a factor that influences the total seepage loss on an individual farm. Under normal conditions an analysis of the time that water is in ditches on a farm shows that when irrigating, on the average, only half of the ditches will have water in them at any one time." From this observation it will be assumed that in a gated pipe system

the average pressure required will be one-half the total pressure required for the system. This gives 11.55 feet.

11) Labor Requirements- Buller, Langemeier, and Kasper (1975) state that flood irrigation of corn requires 3.64 manhours per acre. There is no distinction made between gated pipe and siphon tube surface irrigation labor requirements.

Some of the labor activities for the two surface irrigation systems are:

A. Siphon Tube with Open Ditch
   1) Time to cut ditch and prepare it to receive water.
   2) Time to repair ditch during irrigation season.
   3) Time to backfill the ditch before harvest.
   4) Time to change sets- this would depend on set size, changes per day, time to move portable dam, etc.

B. Gated Pipe
   1) Time to lay out pipe.
   2) Time to change sets (more convenient than siphon tube).
   3) Time to take up pipe before harvest.

Operations A1 and A3 require only one person and a tractor to perform whereas operations B1 and B2 require two people minimum and a vehicle to pull the pipe trailer. The total labor hours required for cutting the ditch would probably be less than the time necessary to lay out the gated pipe.

The time to repair the ditch during the irrigation season would be minimal.

The time to change sets would vary considerably between the two systems. For siphon tube irrigation each tube must be moved to conserve water. It is assumed in this analysis that the dam is moved each change. For the gated pipe system, a change of sets is quick and easy. However, this added labor cost for changing sets in siphon tube irrigation could be offset by the excess labor hours required to lay out, pick-up, and store the gated pipe.

For this analysis it will be assumed that the labor requirements for the two systems will be essentially equal.

12) Efficiency of Ditch System (Eff) as a decimal- This variable is one of the most important parts of the analysis and care should be taken to obtain a realistic value. Efficiency (seepage rate) varies with the characteristics of the soil at the ditch bed, length of time the ditch has been in operation, depth to groundwater, amount of sediment contained in the water, depth of water in the ditch, temperature of the water and of the soil, percentage of entrained air in the soil, capillary tension in the soil, and barometric pressure. A series of on-farm tests of irrigation ditches were made by Dickerson (1964) involving several soil types and which measured seepage and evaporation. The results are given in Table 2.

Table 2. Seepage Rates for Various Soils. From Dickerson (1964).

Soil Type	No. Tests	Avg. %Loss/1000ft.	Range % Loss
Richfield sl	4	7.5	4.6-10.5
Ulysses sl	5	2.8	1.0-4.4
Dalhart fsl	2	1.5	1.0-2.0

Each 1000 feet of ditch must be considered independently in estimating losses. As water proceeds down the ditch, the percentage loss is reduced because the wetted area is constantly being reduced due to a decrease in volume and water depth. An equation for this relationship was derived by Chung (1981) and is as follows:

$$Q' = Q\ (1-S)^{L/1000} \qquad (1)$$

where Q' = flow rate out of ditch in g.p.m. or ft^3/minute.

Q = flow rate into ditch in g.p.m. or ft^3/min.

S = seepage rate as a decimal.

L = length of ditch (feet).

However, due to the earlier stated observation that, on the average, only one-half of the ditches will have water in them at any one time, efficiency of ditch system will be calculated using one-half the total length of ditch:

$$Q' = Q\ (1-S)^{L/2000} \qquad (2)$$

Each soil type will have its own water intake characteristics. The difference in intake between some soils is so minor that for irrigation purposes several soils can be grouped together. The Soil Conservation Service (1975) has grouped soils into 7 intake families designated 0.1, 0.3, 0.5, 1.0, 1.5, 2.0, and 3.0. These designations relate generally to the intake rate of the soil in inches per hour after several hours of water intake. However, Dickerson (1964) states that intake rate varies with time as intake continues, being faster at first and slowing to a fairly constant rate after several hours.

The three soils listed in Table 2 represent three separate soil intake families. Tables 9, 10, and 11 in the appendix give soil series names in the 0.3, 0.5, and 1.0 intake families. It is assumed in this analysis that the soils in each intake family will react similarly as their member in Table 2.

It is also stated by Dickerson (1964) that time is a factor in rate of seepage from canals because of changes that occur in bed material with the lapse of time. Water moving into the soil carries small particles in suspension and deposits them in pore spaces, gradually reducing the soils porosity. In this analysis, due to the lack of data to determine the decrease in seepage with time, it is assumed that seepage remains constant throughout time.

13) Cost of Fuel (C) in dollars per expressed unit- Five different fuels will be included in this analysis and each will have its own symbol:

Cg = cost of natural gas, $/1000ft.^{3}

Ckw = cost of electricity, $/KWH

Cp = cost of propane, $/gallon

Cd = cost of diesel, $/gallon

CG = cost of gasoline, $/gallon

With all of the previous 13 variables examined and explained a breakeven energy cost equation was derived by Nixon (1979). It is arranged in a manner which allows the farmer to input the correct values for his operation and gives a result in dollars per unit energy. The equation is arranged in this manner due to the fact that energy costs are changing faster than the other inputs to the equation.

The equation is:

$$C = \frac{L \times P \times (1+.055 \times I \times LF) \times 3960 \times EP}{LF \times W_c \times T \times (H-Eff \times (H+H_p-W_c \times (1-Eff)/S_c))} \quad (3)$$

If the calculated result is less than the true price of the fuel, then it is economical to replace the open ditch with gated pipe simply from a cost of pumping standpoint. Various examples are worked out and expressed in Table 3.

From the worked examples it can easily be seen that the equation is very sensitive to changes in single variables and that under some conditions it is economical to replace an open ditch with gated pipe and under other conditions it is not economical. The most important equation

Table 3. Breakeven Energy Cost Equation Examples.

Variable	Example 1	Example 2	Example 3	Example 4
L	2600	2600	5200	5200
P	3.00	3.00	3.00	3.00
LF	10	10	10	10
I	.15	.15	.15	.15
W_c	1300	1300	1300	1300
T	1000	1500	1000	1500
H	225	225	225	225
H_p	11.55	11.55	11.55	11.55
S_c	20	20	20	20
Soil	Richfield sl	Richfield sl	Richfield sl	Richfield sl
Eff.	.904	.904	.817	.817
	Breakeven Energy Costs			
Cg	$10.21	$6.81	$8.28	$5.52
Ckw	0.135	0.09	0.11	0.07
Cp	1.05	0.70	0.85	0.57
Cd	1.67	1.12	1.36	0.90
CG	1.33	0.88	1.07	0.72

is the one that would include the true variables for a farmers situation. Quickly and easily, by plugging in his variables, a result can be obtained which may help him decide to change his system or to leave it as is.

As prices for energy continue to rise it will become economical in an increasing number of situations to replace an open ditch with gated pipe. The price of gated pipe is fixed when it is purchased, and although it may not be immediately cost effective, it could as energy prices increase.

As the examples show, if the resultant value for fuel/unit is less than the current price of the fuel/unit, then it is cost-effective to change to gated pipe. The irrigator is wasting water and money under these conditions if he does not change to pipe. If the result is greater than current fuel/unit prices, then it cannot be justified by a cost of pumping analysis to replace ditch with pipe. However, the irrigator may feel that in the near future it will become economical for his conditions and go to pipe anyway.

The breakeven energy cost equation was entered into a computer and the inputs to the equation were held constant or limited to a reasonable range as follows:

L = 2600 ft.

P = \$3.00/ft.

I = .14

LF = 10 years

EP = see Table 1, varied for each fuel

W_c = 500 g.p.m. - 1500 g.p.m. with increments of 100 g.p.m.

T = 1500 hours

H = 25 ft. - 400 ft. with increments of 25 ft.

Eff. = .904 for Richfield sl
.964 for Ulysses sl
.981 for Dalhart fsl

H_p = 11.55 ft.

S_c = 20 g.p.m./ft.

The results to this computer run are summarized in the appendix and a family of curves for the Richfield sl soil and each fuel are graphed in Figures 1 - 5 on the following pages. The results for the Ulysses sl and the Dalhart fsl were in most cases not cost effective at current prices so they are not graphed.

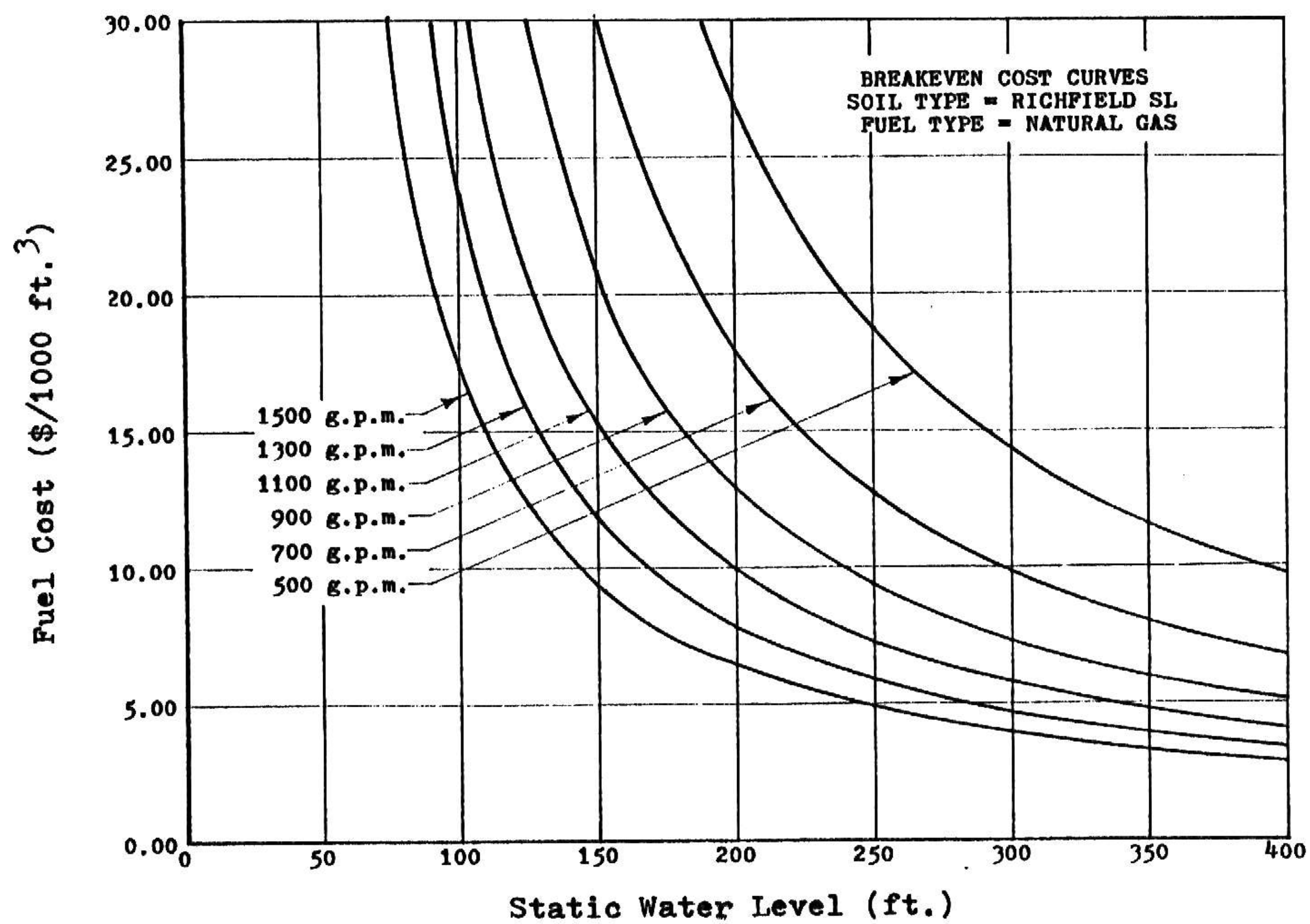

Figure 1. Breakeven Energy Cost Curves for Richfield sl, Natural Gas

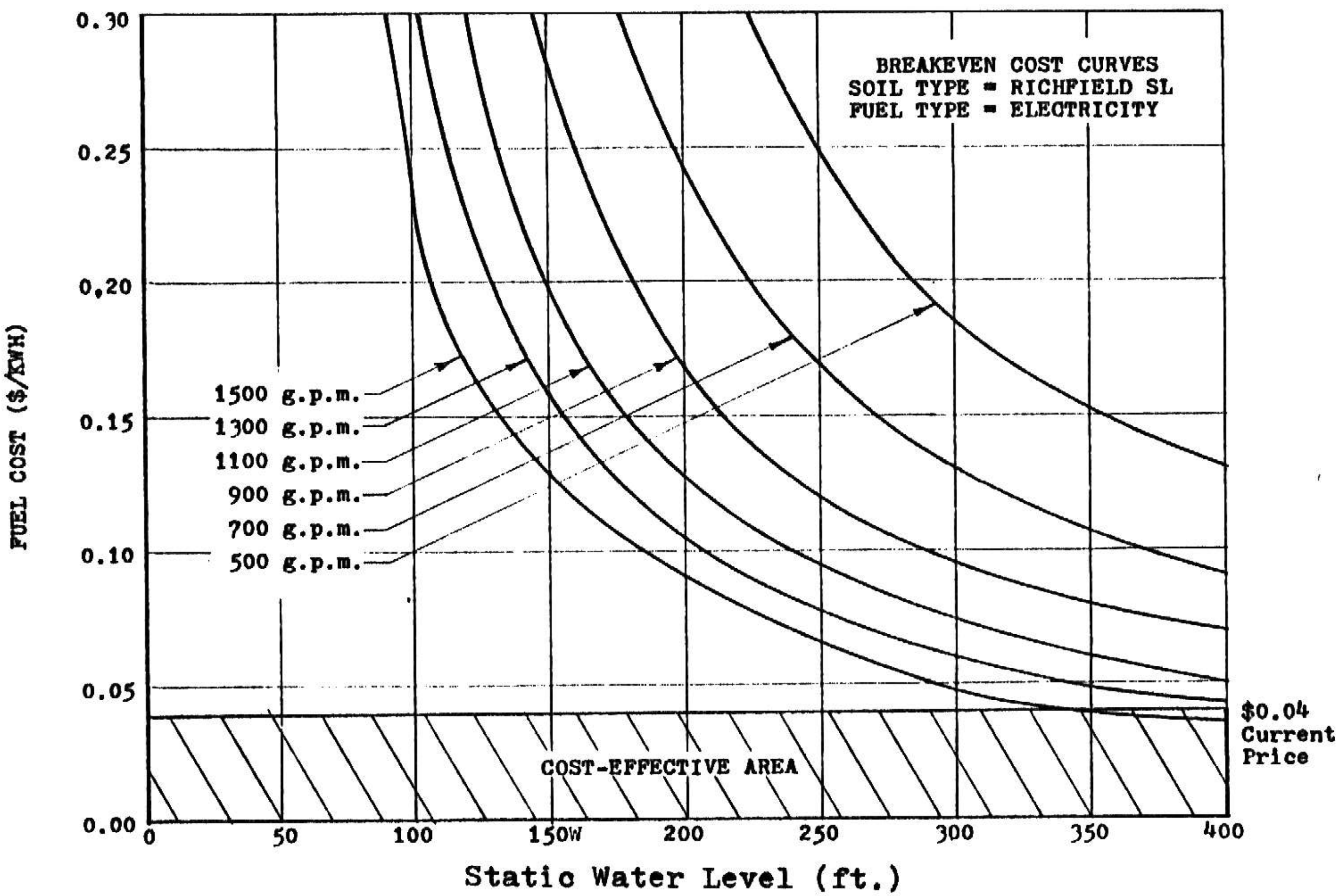

Figure 2. Breakeven Energy Cost Curves for Richfield sl, Electricity

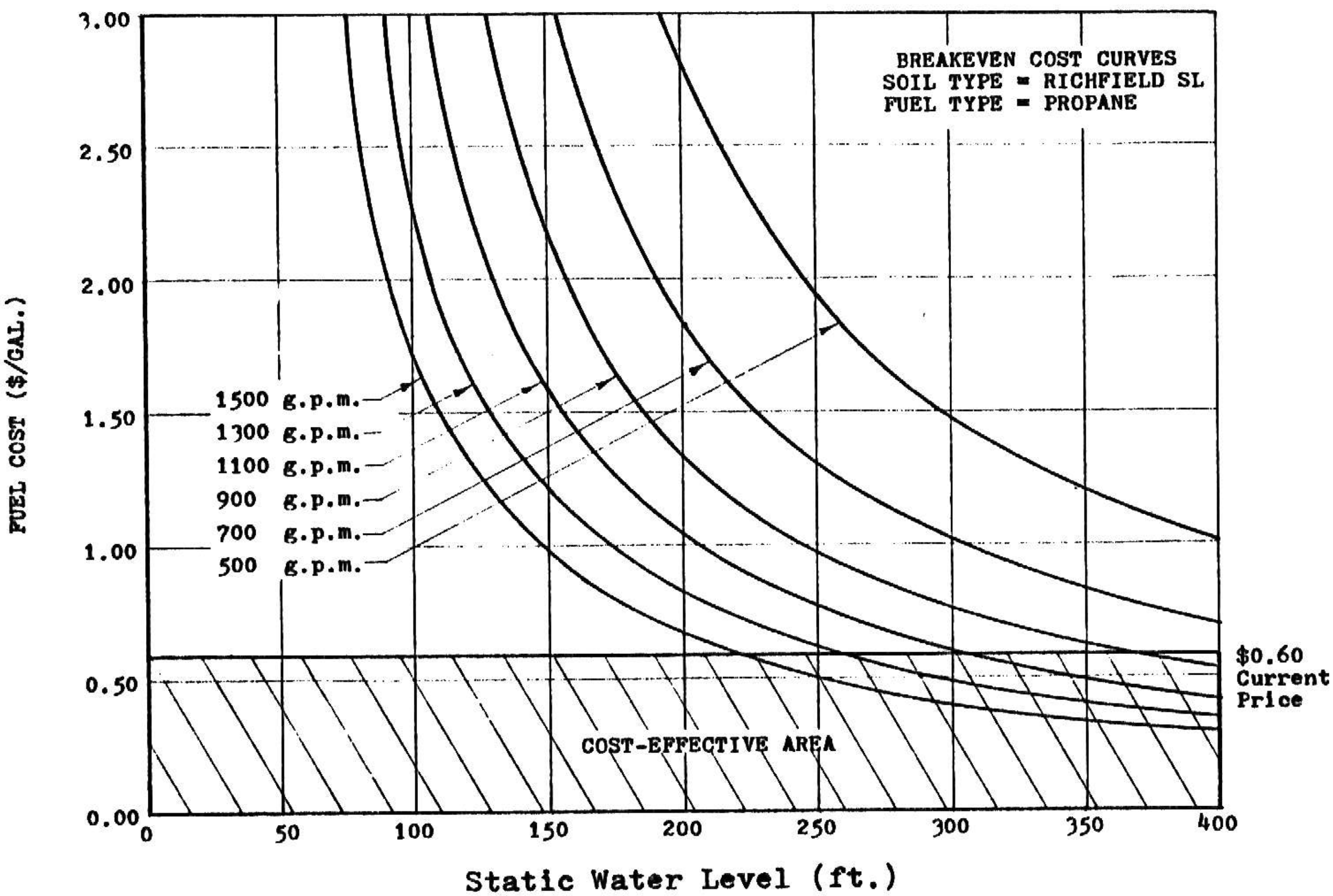

Figure 3. Breakeven Energy Cost Curves for Richfield sl, Propane

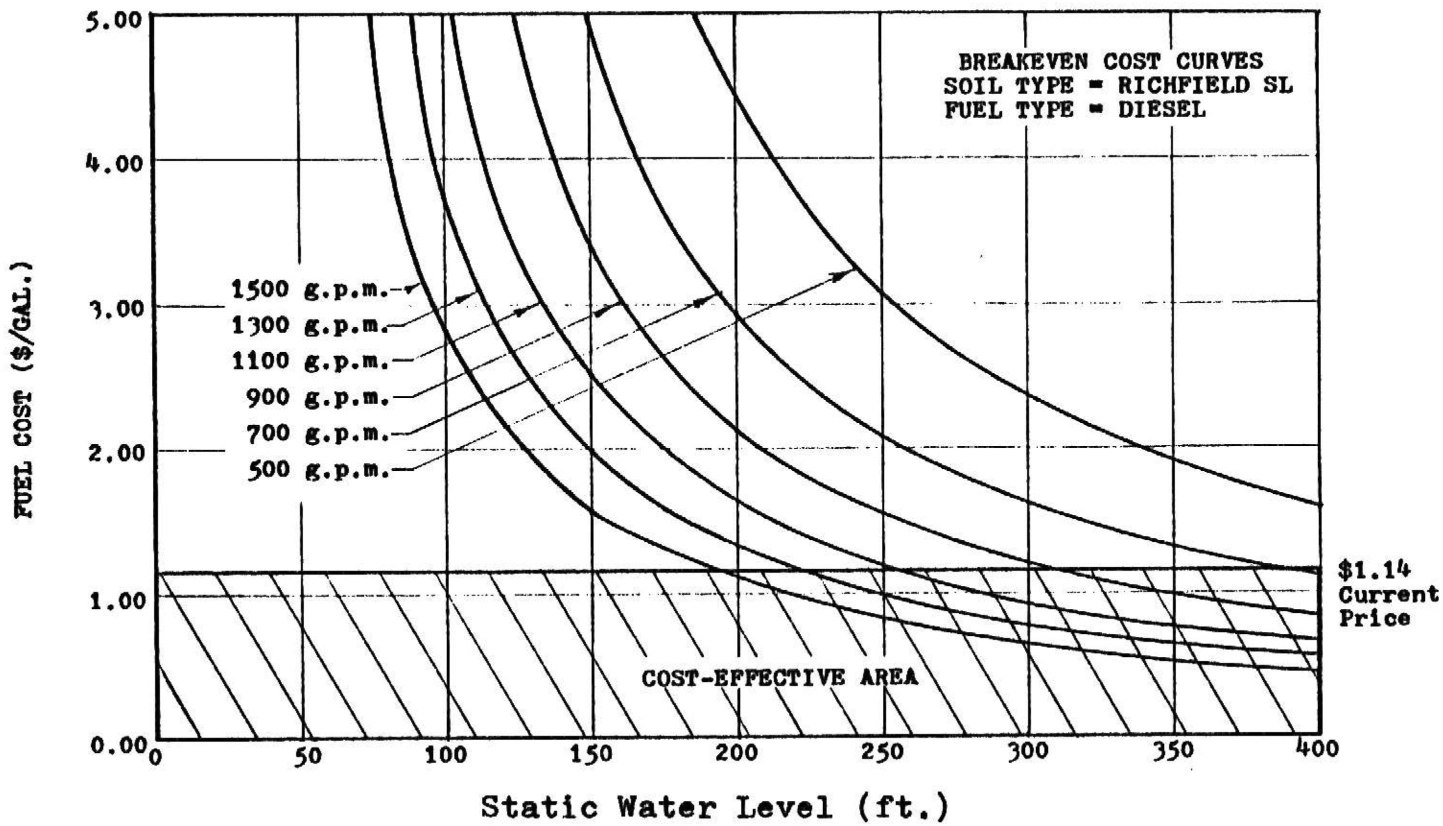

Figure 4. Breakeven Energy Cost Curves for Richfield sl, Diesel

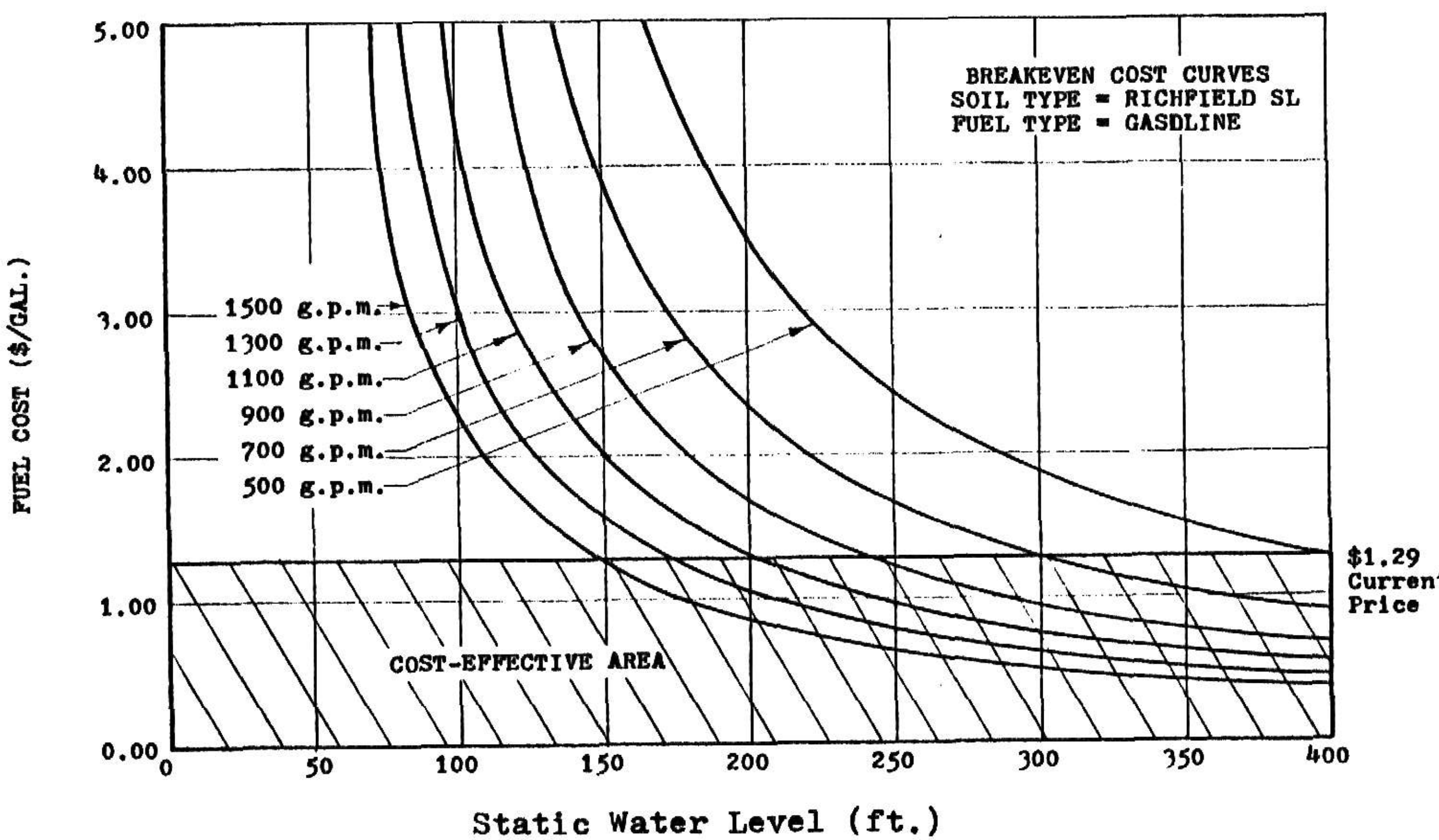

Figure 5. Breakeven Energy Cost Curves for Richfield sl, Gasoline

Cost of Water Loss Based on Potential Productivity

In the preceding sections, the cost of water loss from an open ditch was examined using the breakeven energy cost equation. In this cost approach, cost of water loss based on potential productivity, the cost of water loss from open irrigation ditches will be determined by examining the revenue (dollars) that could be generated if the water loss were conserved and applied to the production of a crop. Corn, soybeans, alfalfa, grain sorghum, and wheat are the crops used to determine the value of this lost water. The method of developing this cost approach is to estimate the possible yield increase over dryland yields that could be expected by beneficial application of the water wasted in the open ditch system (assuming gated pipe is used to apply the wasted water). In tables 4 through 8 the results of this approach are given. The net income resulting from utilization of the water loss in the production of each crop was derived by determining the number of acres that could be irrigated by the quantity of water lost from a half-mile irrigation ditch carrying 1300 g.p.m. in 1500 hours on each soil type. Each crop had different water requirements as indicated by USDA-Soil Conservation Service (1977), and therefore varying acreages for each crop could be irrigated with a fixed amount of water. Net irrigation requirements were determined for Garden City, Kansas in normal rainfall years. Corn requires 16 inches of irrigation and its critical growth periods are tasseling, silk stage, and grain formation. Grain sorghum requires 12 inches of irrigation and its critical growth periods are boot, bloom, and milk-dough stages. Alfalfa requires 22 inches of irrigation with seedling and immediately after cuttings being critical. Soybeans require 14 inches of irrigation with early bloom and seed forming critical. Wheat requires 10 inches with boot, bloom, and early head stage being critical growth periods. The irrigation water should be applied before planting if necessary and then immediately before the critical growth periods of each crop. Any additional water should be applied during serious moisture stress periods.

To determine the number of acres of each crop that can be irrigated, the total acre-feet of water lost from irrigation ditches on each soil type is divided by the gross quantity of water used to irrigate each crop. An overall irrigation efficiency of 70% will be assumed on land that has been leveled with gated pipe in use and with drainage system to design standards as in USDA-Soil Conservation Service (1977), without a tailwater recovery pit. For example, corn requires a net irrigation of 16 inches, which means that a gross irrigation of 22.9 inches is necessary for the 70% efficient system. On a Richfield sl soil which had a water loss of 34.6 acre-feet (Table 4), this would allow 18.1 additional acres to be irrigated.

With this amount of irrigation the corn would be expected to yield 130 bushels per acre as indicated by Pretzer (1979). Therefore, by applying the quantity of water lost from a half-mile irrigation ditch carrying 1300 g.p.m. for 1500 hours, constructed in Richfield sl soil, on 18.1 acres, the gross yield would be 2,353 bushels; resulting in an annual gross income of $7,647.25, assuming that the price of corn is $3.25/bushel.

Annual variable crop production costs such as labor, seed, herbicide, insecticide, fertilizer, fuel and oil for crop production, crop machinery repairs, drying for corn and grain sorghum, miscellaneous, and interest on 1/2 variable costs @ 13%, are estimated from Kansas State University Cooperative Extension Service Management Guides (1980). For corn these variable costs total $158.65 per acre which when multiplied by 18.1 acres gives total annual variable costs of $2,871.57. These variable costs, not including pipe costs, are subtracted from annual gross income giving a result which will be called annual net income to pipe. Fixed costs are not dealt with in this analysis because it is assumed that the irrigator already has the land and machinery capacity to farm the additional acreage, and these costs will be levied against him whether he farms the additional acres or does not farm them.

Annual net income to pipe is then divided by the total length of pipe necessary for the original field (2600 feet), and the additional acreage (varies), giving a result which is annual net income to pipe per foot. Assuming that 2600 feet of pipe irrigates 160 acres it can be calculated that 18.1 acres will require 294 feet of gated pipe, giving a total pipe length for corn of 2,894 feet. Annual net income to pipe for corn is $4775.68 ($7,647.25 - $2,871.57), so annual net income to pipe per foot is $1.65 ($4,775.68/2,894 ft.). This can be equated to the affordable purchase price of the gated pipe multiplied by the capital recovery factor, which takes into account the interest rate and the life of the pipe. The capital recovery factor (CRF) equation is:

$$CRF = \frac{i\ (1 + i)^n}{(1 + i)^n - 1} \tag{4}$$

where i = interest rate

n = life of system component (gated pipe)

For this analysis the interest rate will be fixed at 13% and the life of the gated pipe is 10 years, giving a CRF of 0.184. With annual net income to pipe per foot equal to $1.65 and CRF equal to 0.184, the affordable purchase price of gated pipe per foot is $8.97. The remaining four crops are analyzed in this same manner with the results illustrated in tables 4 through 8.

Table 4. Cost of Water Loss Based on Potential Productivity-Corn

Soil Type	Richfield sl	Ulysses sl	Dalhart fsl
Acre-feet of water lost in 2600 feet of ditch in 1500 hours.	34.6	13.0	7.0
Gross irrigation requirement (inches).	22.9	22.9	22.9
Additional acres able to be irrigated.	18.1	6.8	3.7
Expected yield (bu./acre).	130	130	130
Gross yield (bushels).	2353	884	481
Crop price ($/bushel).	3.25	3.25	3.25
Gross income ($).	7647.25	2873.00	1563.25
Annual variable crop production costs ($/acre).	158.65	158.65	158.65
Total annual variable crop production costs ($).	2871.57	1078.82	587.01
Annual net income to pipe ($).	4775.68	1794.18	976.24
Total length of pipe for original field and additional acres (feet).	2894	2711	2660
Annual net income to pipe per foot ($).	1.65	0.66	0.37
CRF	.184	.184	.184
Affordable purchase price ($/foot of pipe).	8.97	3.59	2.01

Table 5. Cost of Water Loss Based on Potential Productivity-Grain Sorghum

Soil Type	Richfield sl	Ulysses sl	Dalhart fsl
Acre-feet of water lost in 2600 feet of ditch in 1500 hours.	34.6	13.0	7.0
Gross irrigation requirement (inches).	17.1	17.1	17.1
Additional acres able to be irrigated.	24.3	9.1	4.9
Expected yield (bu./acre).	115	115	115
Gross yield (bushels).	2795	1047	564
Crop price ($/bushel).	2.90	2.90	2.90
Gross income ($).	8105.50	3036.30	1635.60
Annual variable crop production costs ($/acre).	120.00	120.00	120.00
Total annual variable crop production costs ($).	2916.00	1092.00	588.00
Annual net income to pipe ($).	5189.50	1944.30	1047.60
Total length of pipe for original field and additional acres (feet).	2995	2748	2680
Annual net income to pipe per foot ($).	1.73	0.71	0.39
CRF	.184	.184	.184
Affordable purchase price ($/foot of pipe).	9.40	3.86	2.12

Table 6. Cost of Water Loss Based on Potential Productivity-Alfalfa

Soil Type	Richfield sl	Ulysses sl	Dalhart fsl
Acre-feet of water lost in 2600 feet of ditch in 1500 hours.	34.6	13.0	7.0
Gross irrigation requirement (inches).	31.4	31.4	31.4
Additional acres able to be irrigated.	13.2	5.0	2.7
Expected yield (tons/acre).	8	8	8
Gross yield (tons).	105.6	40.0	21.6
Crop price ($/ton).	50.00	50.00	50.00
Gross income ($).	5280.00	2000.00	1080.00
Annual variable crop production costs ($/acre).	72.21	72.21	72.21
Total annual variable crop production costs ($).	953.17	361.05	194.97
Annual net income to pipe ($).	4326.83	1638.95	885.03
Total length of pipe for original field and additional acres (feet).	2815	2681	2644
Annual net income to pipe per foot ($).	1.54	0.61	0.33
CRF	.184	.184	.184
Affordable purchase price ($/foot of pipe).	8.37	3.32	1.79

Table 7. Cost of Water Loss Based on Potential Productivity-Soybeans

Soil Type	Richfield sl	Ulysses sl	Dalhart fsl
Acre-feet of water lost in 2600 feet of ditch in 1500 hours.	34.6	13.0	7.0
Gross irrigation requirement (inches).	20.0	20.0	20.0
Additional acres able to be irrigated.	20.8	7.8	4.2
Expected yield (bu./acre).	45	45	45
Gross yield (bu.)	936	351	189
Crop price ($/bu.).	7.20	7.20	7.20
Gross income ($).	6739.20	2527.20	1360.80
Annual variable crop production costs ($/acre).	81.75	81.75	81.75
Total annual variable crop production costs ($).	1700.40	637.65	343.35
Annual net income to pipe ($).	5038.80	1889.55	1017.45
Total length of pipe for original field and additional acres (feet).	2938	2727	2668
Annual net income to pipe per foot ($).	1.72	0.69	0.38
CRF	.184	.184	.184
Affordable purchase price ($/foot of pipe).	9.35	3.75	2.07

Table 8. Cost of Water Loss Based on Potential Productivity-Wheat

Soil Type	Richfield sl	Ulysses sl	Dalhart fsl
Acre-feet of water lost in 2600 feet of ditch in 1500 hours.	34.6	13.0	7.0
Gross irrigation requirement (inches).	14.3	14.3	14.3
Additional acres able to be irrigated.	29.0	10.9	5.9
Expected yield (bu./acre).	55	55	55
Gross yield (bu.).	1595	600	325
Crop price ($/bu.).	4.20	4.20	4.20
Gross income ($).	6699.00	2520.00	1365.00
Annual variable crop production costs ($/acre).	62.00	62.00	62.00
Total annual variable crop production costs ($).	1798.00	675.80	365.80
Annual net income to pipe ($).	4901.00	1844.20	999.20
Total length of pipe for original field and additional acres (feet).	3071	2777	2696
Annual net income to pipe per foot ($).	1.60	0.66	0.37
CRF	.184	.184	.184
Affordable purchase price ($/foot of pipe).	8.70	3.59	2.01

DISCUSSION

From previous research by Dickerson (1964) it was found that seepage from earth ditches resulted in loss of a large portion of water used for irrigation. Three soil types were dealt with in this investigation. It was found that there was quite a bit of variation in losses depending on the soil type.

This report examined the economics of switching from an open ditch surface irrigation system to a gated pipe surface irrigation system from two standpoints. The first was a cost of pumping the wasted water approach and was developed with a breakeven energy cost equation which would be applicable to most any surface irrigation situation in the midwest. It was found that the cost-effectiveness of switching to gated pipe varied with soil type, hours of use, length of ditch, depth to water, type of fuel, and many other factors. Soil type was the primary determinant of cost-effectiveness.

In the second approach the potential productivity of the water wasted by open ditches in various soils was examined and found to be significant in both potential production of a given commodity and the dollar profit value from this production.

CONCLUSIONS

From the computations concerning the cost of water loss based on pumping costs, it is obvious that under some present conditions it is cost-effective to switch from an open ditch to a gated pipe system. For instance, on a Richfield sl soil with a diesel fueled power source, a 250 foot well depth, pumping 1300 g.p.m., it can be seen from Figure 4 and the appendix that the breakeven energy cost is $0.97. With the present price of diesel fuel at $1.14 it is cost-effective to switch to gated pipe.

Under some other criteria it may not be at all close to being cost-effective to make the switch from open ditch to gated pipe or it may be very close but not cost-effective quite yet. Assuming that energy costs will continue to rise, irrigators whose system criteria show that it is cost-effective or is fairly close to being cost-effective, should definitely replace their open ditches with gated pipe. Otherwise they are wasting water, money, and grain.

If a system is not anywhere near being cost-effective (as is the case with the Dalhart fsl and all conditions computed) it still may be wise to switch to gated pipe. Justifications for switching to gated pipe when it is not cost-effective are to conserve water and to conserve labor hours during the growing season due to the fact that it takes less time to change sets with gated pipe than it does with an open ditch. Another basis of justifying the switch may be found in tables 4 through 8. The potential productivity of the wasted water in an open ditch system may be very great as the gated pipe may provide for an annual net income of $5189.50 over that of an open ditch system, in the case of the Richfield sl soil and grain soughum. These three items are responsible for much of the increased use of gated pipe in the past and will continue to be in situations where it is not cost-effective to switch to gated pipe.

One thing is for certain: Water is becoming a scarce and expensive resource in some areas and any measure by irrigator's to conserve water, whether it is by switching to gated pipe, decreasing runoff, planting low water-use crops, etc., will keep them in business longer without lawmakers getting into the picture and telling them what they can and cannot do.

SUGGESTIONS FOR FUTURE RESEARCH

The calculations in this investigation are based on the results of seepage tests on three soil types only, and of limited duration. Additional seepage studies need to be made in order to determine more accurately the range of losses to be expected on many different soil types and the variation in seepage rates with time. Long-term continuous-flow tests on selected ditches in principal soil types need to be made.

Irrigators need to be made aware of the results of this report so they can analyze their systems and see for themselves the water and profit potential they are wasting. The extension service should be able to easily convert the material in this report into a concise, easily understood publication.

The feasibility and farming practices necessary for limited surface irrigation need to be researched. The method of water conveyance from irrigated fields to tailwater pits (runoff) is presently open ditch which has been shown to be inefficient. Also, these tailwater pits are subject to seepage and evaporation. If a serious effort to conserve irrigation water is to be made then runoff and tailwater pits must be abolished. This will necessitate more advanced field leveling techniques and the planting of crops that can survive with little irrigation, so that if water flow is depressed at the low end of the field, the crop will still survive. This may induce the planting of two crops in one field with the high water requirement crop close to the water source and the less water needy crop at the end of the field away from the water source.

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APPENDIX

Table 9. Intake Family 0.3
Information from USDA-Soil Conservation Service (1977).

Deep soils with silt loam, loam, slay loam, or silty clay loam surface layers and clay loam, silty clay loam or silty clay subsoils. Subsoil permeability is slow to moderately slow. Shrinkage cracks that result from drying in the soils with more clayey subsoil textures allow water acceptance sufficient for this design.

Depth	Available Water Capacity
1'	2.3"
2'	4.3"
3'	6.3"
4'	8.4"
5'	10.6"

Bethany silt loam
Blanket silt loam
Bowdoin loamy fine sand
Bremer silty clay loam
Brewer silty clay loam
Carlson silt loam
Carwile fine sandy loam
Chase silty clay loam
Church silty clay loam
Crete silt loam
Dennis silt loam
Detroit silty clay loam
Drummond silt loam
Gymer silt loam
Harney silt loam
Hastings silt loam
Kimo silty clay loam
Lanton silty clay loam
Lubbock silty clay loam
Martin silty clay loam
Mento silt loam
Missler silty clay loam
Okemah silt loam
RICHFIELD SILT LOAM
Ryus silty clay loam
Sharpsburg silty clay loam
Summit silty clay loam
Tully silty clay loam

Table 10. Intake Family 0.5
Information from USDA-Soil Conservation Service (1977).

Deep soils with silt loam, loam, clay loam or silty clay loam surface layers and subsoils. Subsoil permeability is moderate to moderately slow.

Depth	Available Water Capacity
1'	2.5"
2'	4.9"
3'	7.1"
4'	9.4"
5'	11.7"

Angelus silt loam
Armo loam
Bippus clay loam
Bridgeport silt loam
Burchard clay loam
Caruso loam
Case clay loam
Clairemont silt loam
Clark clay loam
Colby silt loam
Coly silt loam
Corbin silt loam
Cozad silt loam
Dale clay loam
Elkader silt loam
Elmont silt loam
Eltree silt loam
Farnum loam
Geary silt loam
Goshen silt loam
Grant silt loam
Grigston silt loam
Hall silt loam
Hepler silt loam
Hobbs silt loam
Holdrege silt loam
Hord silt loam
Humbarger loam
Ivan silt loam
Judson silt loam
Kahola silt loam
Kaski loam
Keith silt loam
Kennebec silt loam
Kim clay loam
Leshara clay loam
Lula silt loam
Mansic clay loam
Manvel silt loam
Mason silt loam
McCune silt loam
Milan loam
Minnequa silt loam
Monona silt loam
Morrill loam
Muir silt loam
Norge silt loam
Nuckolls silt loam
Ost clay loam
Penden clay loam
Pond Creek silt loam
Port silt loam
Radley silt loam
Reading silt loam
Richfield loamy fine sand
Roxbury silt loam
Ruella loam
Satanta loam
Shelby loam
Tobin silt loam
Uly silt loam
ULYSSES SILT LOAM
Vanoss silt loam
Verdigris silt loam
Zenda clay loam

Table 11. Intake Family 1.0
Information from USDA-Soil Conservation Service (1977)

Deep soils with silt loam, loam or very fine sandy loam surface layers and moderately permeable, medium textured subsoils.

Depth	Available Water Capacity
1'	2.0"
2'	4.0"
3'	5.9"
4'	7.8"
5'	9.4"

Cleora fine sandy loam
DALHART FINE SANDY LOAM
Eudor silt loam
Haynie silt loam
Kenesaw silt loam
Konawa fine sandy loam
Manter fine sandy loam
McCook silt loam
Minco silt loam
Naron fine sandy loam
Reinach silt loam
Shellabarger fine sandy loam

SOIL TYPE = RICHFIELD S1
FUEL TYPE = NATURAL GAS

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-50.39	-85.22	-276.08	222.71	79.35	48.28	34.69	27.07	22.20	18.81	16.32	14.41	12.90	11.68	10.67	9.82
600	-45.34	-81.16	-386.62	139.90	59.23	37.57	27.51	21.70	17.91	15.25	13.28	11.76	10.55	9.57	8.75	8.07
700	-42.23	-81.16	-1037.11	96.22	45.98	30.20	22.49	17.91	14.89	12.73	11.12	9.88	8.88	8.07	7.39	6.82
800	-40.46	-85.22	803.37	70.30	36.76	24.89	18.81	15.12	12.64	10.86	9.52	8.47	7.63	6.94	6.37	5.88
900	-39.74	-94.68	247.50	53.64	30.08	20.90	16.01	12.98	10.71	9.41	8.27	7.38	6.66	6.07	5.58	5.16
1000	-39.96	-113.61	134.72	42.29	25.08	17.83	13.83	11.29	9.54	8.26	7.29	6.52	5.89	5.38	4.95	4.58
1100	-41.15	-154.91	87.78	34.20	21.24	15.40	12.08	9.94	8.44	7.34	6.49	5.81	5.27	4.81	4/43	4.11
1200	-43.49	-283.93	62.71	28.24	18.22	13.45	10.66	8.83	7.53	6.57	5.82	5.23	4.75	4.35	4.01	3.72
1300	-47.41	-477689.56	47.42	23.71	15.00	11.85	9.48	7.90	6.77	5.93	5.27	4.74	4.31	3.95	3.65	3.39
1400	-53.74	243.64	37.29	20.19	13.84	10.53	8.50	7.12	6.13	5.30	4.80	4.32	3.94	3.61	3.34	3.10
1500	-64.35	113.67	30.18	17.40	12.22	9.42	7.66	6.46	5.50	4.91	4.39	3.97	3.62	3.32	3.08	2.86

SOIL TYPE = RICHFIELD S1
FUEL TYPE = ELECTRICITY

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-0.67	-1.13	-3.66	2.96	1.05	0.64	0.46	0.36	0.29	0.25	0.22	0.19	0.17	0.15	0.14	0.13
600	-0.60	-1.08	-5.13	1.86	0.79	0.50	0.36	0.29	0.24	0.20	0.18	0.16	0.14	0.13	0.12	0.11
700	-0.56	-1.08	-13.76	1.28	0.61	0.40	0.30	0.24	0.20	0.17	0.15	0.13	0.12	0.11	0.10	0.09
800	-0.54	-1.13	10.66	0.93	0.49	0.33	0.25	0.20	0.17	0.14	0.13	0.11	0.10	0.09	0.08	0.08
900	-0.53	-1.26	3.29	0.71	0.40	0.28	0.21	0.17	0.14	0.12	0.11	0.10	0.09	0.08	0.07	0.07
1000	-0.53	-1.51	1.79	0.56	0.33	0.24	0.18	0.15	0.13	0.11	0.10	0.09	0.08	0.07	0.07	0.06
1100	-0.55	-2.06	1.16	0.45	0.28	0.20	0.16	0.13	0.11	0.10	0.09	0.08	0.07	0.06	0.06	0.05
1200	-0.58	-3.77	0.83	0.37	0.24	0.18	0.14	0.12	0.10	0.09	0.08	0.07	0.06	0.06	0.05	0.05
1300	-0.63	-6338.16	0.63	0.31	0.21	0.16	0.13	0.10	0.09	0.08	0.07	0.06	0.06	0.05	0.05	0.04
1400	-0.71	3.23	0.49	0.27	0.18	0.14	0.11	0.09	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.04
1500	-0.85	1.51	0.40	0.23	0.16	0.13	0.10	0.09	0.07	0.07	0.06	0.05	0.05	0.04	0.04	0.04

SOIL TYPE = RICHFIELD SI
FUEL TYPE = PROPANE

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-5.20	-8.80	-28.52	23.01	8.20	4.99	3.58	2.80	2.29	1.94	1.69	1.49	1.33	1.21	1.10	1.01
600	-4.68	-8.38	-39.94	14.45	6.12	3.88	2.84	2.24	1.85	1.58	1.37	1.21	1.09	0.99	0.90	0.83
700	-4.36	-8.38	-107.13	9.94	4.75	3.12	2.32	1.85	1.54	1.32	1.15	1.02	0.92	0.83	0.76	0.70
800	-4.18	-8.80	82.99	7.26	3.80	2.57	1.94	1.56	1.31	1.12	0.98	0.87	0.79	0.72	0.66	0.61
900	-4.11	-9.78	25.57	5.54	3.11	2.16	1.65	1.34	1.13	0.97	0.85	0.76	0.69	0.63	0.58	0.53
1000	-4.13	-11.74	13.92	4.37	2.59	1.84	1.43	1.17	0.99	0.85	0.75	0.67	0.61	0.56	0.51	0.47
1100	-4.25	-16.00	9.07	3.53	2.19	1.59	1.25	1.03	0.87	0.76	0.67	0.60	0.54	0.50	0.46	0.42
1200	-4.49	-29.33	6.48	2.92	1.88	1.39	1.10	0.91	0.78	0.68	0.60	0.54	0.49	0.45	0.41	0.38
1300	-4.90	-49344.55	4.90	2.45	1.63	1.22	0.98	0.82	0.70	0.61	0.54	0.49	0.45	0.41	0.38	0.35
1400	-5.55	25.17	3.85	2.09	1.43	1.09	0.88	0.74	0.63	0.56	0.50	0.45	0.41	0.37	0.35	0.32
1500	-6.65	11.74	3.12	1.80	1.26	0.97	0.79	0.67	0.58	0.51	0.45	0.41	0.37	0.34	0.32	0.30

SOIL TYPE = RICHFIELD SI
FUEL TYPE = DIESEL

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-8.26	-13.98	-45.28	36.53	13.01	7.92	5.69	4.44	3.64	3.09	2.68	2.36	2.12	1.92	1.75	1.61
600	-7.44	-13.31	-63.41	22.95	9.72	6.16	4.51	3.56	2.94	2.50	2.18	1.93	1.73	1.57	1.44	1.32
700	-6.93	-13.31	-170.11	15.78	7.54	4.95	3.69	2.94	2.44	2.09	1.82	1.62	1.46	1.32	1.21	1.12
800	-6.64	-13.98	131.77	11.53	6.03	4.08	3.09	2.48	2.07	1.78	1.56	1.39	1.25	1.14	1.04	0.96
900	-6.52	-15.53	40.59	8.80	4.93	3.43	2.63	2.13	1.79	1.54	1.36	1.21	1.09	1.00	0.91	0.85
1000	-6.55	-18.63	22.10	6.94	4.11	2.92	2.27	1.85	1.57	1.36	1.20	1.07	0.97	0.88	0.81	0.75
1100	-6.75	-25.41	14.40	5.61	3.48	2.53	1.98	1.63	1.38	1.20	1.06	0.95	0.86	0.79	0.73	0.67
1200	-7.13	-46.57	10.28	4.63	2.99	2.21	1.75	1.45	1.24	1.08	0.96	0.86	0.78	0.71	0.66	0.61
1300	-7.78	-78349.68	7.78	3.89	2.59	1.94	1.56	1.30	1.11	0.97	0.86	0.78	0.71	0.65	0.60	0.56
1400	-8.81	39.96	6.12	3.31	2.27	1.73	1.39	1.17	1.01	0.88	0.79	0.71	0.65	0.59	0.55	0.51
1500	-10.56	18.64	4.95	2.85	2.00	1.55	1.26	1.06	0.92	0.81	0.72	0.65	0.59	0.55	0.50	0.47

SOIL TYPE = RICHFIELD S1
FUEL TYPE = GASOLINE

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-6.54	-11.06	-35.85	20.92	10.30	6.27	4.50	3.51	2.08	2.44	2.12	1.87	1.68	1.52	1.39	1.27
600	-5.89	-10.54	-50.20	18.16	7.69	4.88	3.57	2.82	2.33	1.98	1.72	1.53	1.37	1.24	1.14	1.05
700	-5.48	-10.54	-134.65	12.49	5.97	3.92	2.92	2.33	1.93	1.65	1.44	1.28	1.15	1.05	0.96	0.89
800	-5.25	-11.06	104.31	9.13	4.77	3.23	2.44	1.96	1.64	1.41	1.24	1.10	0.99	0.90	0.83	0.76
900	-5.16	-12.29	32.13	6.96	3.91	2.71	2.08	1.69	1.42	1.22	1.07	0.96	0.87	0.79	0.72	0.67
1000	-5.19	-14.75	17.49	5.49	3.26	2.31	1.80	1.47	1.24	1.07	0.95	0.85	0.77	0.70	0.64	0.59
1100	-5.34	-20.11	11.40	4.44	2.76	2.00	1.57	1.29	1.10	0.95	0.84	0.75	0.68	0.63	0.58	0.53
1200	-5.65	-36.86	8.14	3.67	2.37	1.75	1.30	1.15	0.90	0.85	0.76	0.68	0.62	0.56	0.52	0.48
1300	-6.16	-62020.87	6.16	3.08	2.05	1.54	1.23	1.03	0.88	0.77	0.68	0.62	0.56	0.51	0.47	0.44
1400	-6.98	31.63	4.84	2.62	1.80	1.37	1.10	0.92	0.80	0.70	0.62	0.56	0.51	0.47	0.43	0.40
1500	-8.36	14.76	3.92	2.26	1.59	1.22	1.00	0.84	0.72	0.64	0.57	0.51	0.47	0.43	0.40	0.37

SOIL TYPE = ULISSES S1
FUEL TYPE = NATURAL GAS

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-31.59	-34.94	-39.10	-44.30	-51.30	-60.79	-74.59	-96.47	-136.55	-233.58	-807.02	554.64	206.40	126.79	91.50	71.58
600	-26.82	-29.73	-33.35	-37.97	-44.08	-52.53	-65.00	-85.22	-123.70	-225.55	-1276.91	340.75	153.42	98.34	72.36	57.24
700	-23.43	-26.03	-29.27	-33.44	-38.99	-46.76	-58.30	-77.70	-116.14	-229.81	-10806.07	240.02	118.69	78.04	59.02	47.17
800	-20.90	-23.27	-26.24	-30.09	-35.25	-42.55	-53.66	-72.62	-112.33	-247.85	1200.96	175.44	94.63	64.79	49.26	39.73
900	-18.95	-21.15	-23.92	-27.52	-32.40	-39.39	-50.22	-69.28	-111.62	-287.08	501.89	133.90	77.26	54.29	41.85	34.05
1000	-17.40	-19.47	-22.08	-25.51	-30.19	-36.99	-47.73	-67.27	-113.08	-370.74	295.26	105.58	64.29	46.21	36.07	29.58
1100	-16.15	-18.11	-20.61	-23.90	-28.46	-35.15	-45.97	-66.39	-119.48	-596.41	199.37	85.41	54.34	39.85	31.46	25.99
1200	-15.12	-17.00	-19.41	-22.61	-27.08	-33.75	-44.79	-66.56	-129.49	-2372.60	145.36	70.52	46.55	34.74	27.71	23.05
1300	-14.26	-16.08	-18.42	-21.56	-25.99	-32.71	-44.13	-67.79	-146.18	936.03	111.39	59.22	40.33	30.58	24.62	20.61
1400	-13.54	-15.30	-17.60	-20.70	-25.13	-31.97	-43.94	-70.21	-174.67	358.07	88.41	50.43	35.28	27.13	22.04	18.55
1500	-12.92	-14.65	-16.91	-20.00	-24.46	-31.49	-44.19	-74.07	-228.60	210.45	72.06	43.47	31.12	24.24	19.85	16.80

SOIL TYPE = ULISSES S1

FUEL TYPE = ELECTRICITY

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-0.42	-0.46	-0.52	-0.59	-0.68	-0.81	-0.99	-1.28	-1.81	-3.10	-10.71	7.36	2.74	1.68	1.21	0.95
600	-0.36	-0.39	-0.44	-0.50	-0.58	-0.70	-0.86	-1.13	-1.64	-2.99	-16.94	4.63	2.04	1.30	0.96	0.76
700	-0.31	-0.35	-0.39	-0.44	-0.52	-0.62	-0.77	-1.03	-1.54	-3.05	-143.38	3.18	1.57	1.05	0.78	0.63
800	-0.28	-0.31	-0.35	-0.40	-0.47	-0.56	-0.71	-0.96	-1.49	-3.29	15.93	2.33	1.26	0.86	0.65	0.53
900	-0.25	-0.28	-0.32	-0.37	-0.43	-0.52	-0.67	-0.92	-1.48	-3.81	6.66	1.78	1.03	0.72	0.56	0.45
1000	-0.23	-0.26	-0.29	-0.34	-0.40	-0.49	-0.63	-0.89	-1.51	-4.92	3.92	1.40	0.85	0.61	0.48	0.39
1100	-0.21	-0.24	-0.27	-0.32	-0.38	-0.47	-0.61	-0.88	-1.59	-7.91	2.65	1.13	0.72	0.53	0.42	0.34
1200	-0.20	-0.23	-0.26	-0.30	-0.36	-0.45	-0.59	-0.88	-1.72	-31.48	1.93	0.94	0.62	0.46	0.37	0.31
1300	-0.19	-0.21	-0.24	-0.29	-0.34	-0.43	-0.59	-0.90	-1.94	12.42	1.48	0.79	0.54	0.41	0.33	0.27
1400	-0.18	-0.20	-0.23	-0.27	-0.33	-0.42	-0.58	-0.93	-2.32	4.75	1.17	0.67	0.47	0.36	0.29	0.25
1500	-0.17	-0.19	-0.22	-0.27	-0.32	-0.42	-0.59	-0.98	-3.03	2.79	0.96	0.58	0.41	0.32	0.26	0.22

SOIL TYPE = ULISSES S1

FUEL TYPE = PROPANE

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-3.26	-3.61	-4.04	-4.58	-5.30	-6.28	-7.70	-9.97	-14.11	-24.13	-83.36	57.29	21.32	13.10	9.45	7.39
600	-2.77	-3.07	-3.44	-3.92	-4.55	-5.43	-6.71	-8.80	-12.78	-23.30	-131.90	36.03	15.85	10.16	7.48	5.91
700	-2.42	-2.69	-3.02	-3.45	-4.03	-4.83	-6.03	-8.03	-12.00	-23.74	-1116.25	24.79	12.26	8.14	6.10	4.87
800	-2.16	-2.40	-2.71	-3.11	-3.64	-4.39	-5.54	-7.50	-11.60	-25.60	124.06	18.12	9.78	6.69	5.09	4.10
900	-1.96	-2.18	-2.47	-2.84	-3.35	-4.07	-5.19	-7.16	-11.53	-29.66	51.84	13.83	7.98	5.61	4.32	3.52
1000	-1.80	-2.01	-2.28	-2.63	-3.12	-3.82	-4.93	-6.95	-11.76	-38.30	30.50	10.91	6.64	4.77	3.73	3.06
1100	-1.67	-1.87	-2.13	-2.47	-2.94	-3.63	-4.75	-6.06	-12.34	-61.61	20.59	8.82	5.61	4.12	3.25	2.68
1200	-1.56	-1.76	-2.00	-2.34	-2.80	-3.49	-4.63	-6.00	-13.38	-245.09	15.02	7.28	4.81	3.59	2.86	2.38
1300	-1.47	-1.66	-1.90	-2.23	-2.68	-3.38	-4.56	-7.00	-15.10	96.69	11.51	6.12	4.17	3.16	2.54	2.13
1400	-1.40	-1.58	-1.82	-2.14	-2.60	-3.30	-4.54	-7.25	-18.04	36.99	9.13	5.21	3.64	2.80	2.28	1.92
1500	-1.33	-1.51	-1.75	-2.07	-2.53	-3.25	-4.57	-7.65	-23.61	21.74	7.44	4.49	3.21	2.50	2.05	1.74

SOIL TYPE = ULISSES S1

FUEL TYPE = DIESEL

WELL DEPTH (ft)

CAPACITY (gpm)	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-5.18	-5.73	-6.41	-7.28	-8.41	-9.97	-12.23	-15.82	-22.40	-30.31	-132.37	90.97	33.85	20.80	15.01	11.74
600	-4.40	-4.88	-5.47	-6.23	-7.23	-8.62	-10.66	-13.98	-20.29	-36.99	-209.44	57.20	25.16	16.13	11.07	9.39
700	-3.84	-4.27	-4.80	-5.40	-6.40	-7.67	-9.58	-12.74	-19.05	-37.69	-1772.39	39.37	19.47	12.93	9.68	7.74
800	-3.43	-3.82	-4.30	-4.93	-5.78	-6.98	-8.80	-11.91	-18.42	-40.65	196.90	28.78	15.52	10.63	8.00	6.52
900	-3.11	-3.47	-3.92	-4.51	-5.31	-6.46	-8.24	-11.36	-18.31	-47.09	82.32	21.96	12.67	8.90	6.86	5.58
1000	-2.85	-3.19	-3.62	-4.10	-4.95	-6.07	-7.83	-11.03	-18.68	-60.01	48.43	17.32	10.54	7.58	5.92	4.85
1100	-2.65	-2.97	-3.38	-3.92	-4.67	-5.77	-7.54	-10.89	-19.60	-97.82	32.70	14.01	8.91	6.54	5.16	4.26
1200	-2.48	-2.79	-3.18	-3.71	-4.44	-5.54	-7.35	-10.92	-21.24	-389.15	23.84	11.57	7.64	5.70	4.55	3.78
1300	-2.34	-2.64	-3.02	-3.54	-4.26	-5.37	-7.24	-11.12	-23.98	153.53	18.27	9.71	6.61	5.01	4.04	3.38
1400	-2.22	-2.51	-2.89	-3.39	-4.12	-5.24	-7.21	-11.52	-28.65	58.73	14.50	8.27	5.79	4.45	3.61	3.04
1500	-2.12	-2.40	-2.77	-3.28	-4.01	-5.17	-7.25	-12.15	-37.49	34.52	11.82	7.13	5.10	3.98	3.26	2.76

SOIL TYPE = ULISSES S1

FUEL TYPE = GASOLINE

WELL DEPTH (ft)

CAPACITY (gpm)	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-4.10	-4.54	-5.08	-5.76	-6.66	-7.89	-9.68	-12.53	-17.73	-30.33	-104.78	72.01	26.80	16.46	11.88	9.29
600	-3.48	-3.86	-4.33	-4.93	-5.72	-6.82	-8.44	-11.06	-16.06	-29.28	-165.79	45.28	19.92	12.77	9.40	7.43
700	-3.04	-3.38	-3.80	-4.34	-5.06	-6.07	-7.50	-10.09	-15.08	-29.84	-1403.01	31.16	15.41	10.24	7.66	6.12
800	-2.71	-3.02	-3.41	-3.91	-4.58	-5.52	-6.97	-9.43	-14.58	-32.18	155.93	22.78	12.29	8.41	6.40	5.16
900	-2.46	-2.75	-3.11	-3.57	-4.21	-5.11	-6.52	-8.99	-14.49	-37.27	65.16	17.38	10.03	7.05	5.43	4.42
1000	-2.26	-2.53	-2.87	-3.31	-3.92	-4.80	-6.20	-8.73	-14.79	-40.14	30.33	13.71	8.35	6.00	4.60	3.84
1100	-2.10	-2.35	-2.68	-3.10	-3.69	-4.56	-5.97	-8.62	-15.51	-77.44	25.88	11.09	7.06	5.17	4.00	3.37
1200	-1.96	-2.21	-2.52	-2.94	-3.52	-4.30	-5.82	-8.64	-16.81	-308.05	18.87	9.16	6.04	4.51	3.60	2.99
1300	-1.85	-2.09	-2.39	-2.80	-3.37	-4.25	-5.73	-8.80	-18.98	121.53	14.46	7.69	5.24	3.97	3.20	2.60
1400	-1.76	-1.99	-2.28	-2.69	-3.26	-4.15	-5.70	-9.12	-22.68	46.49	11.48	6.55	4.58	3.52	2.86	2.41
1500	-1.68	-1.90	-2.20	-2.60	-3.18	-4.09	-5.74	-9.62	-29.68	27.32	9.36	5.64	4.04	3.15	2.58	2.18

SOIL TYPE = DALHART FS1

FUEL TYPE = NATURAL GAS

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-28.48	-29.84	-31.34	-33.00	-34.85	-36.91	-39.24	-41.88	-44.90	-48.38	-52.46	-57.28	-63.09	-70.20	-79.11	-90.62
600	-23.94	-25.10	-26.38	-27.79	-29.36	-31.12	-33.11	-35.36	-37.95	-40.94	-44.45	-48.61	-53.64	-59.82	-67.61	-77.74
700	-20.71	-21.72	-22.84	-24.07	-25.45	-26.99	-28.74	-30.72	-33.00	-35.65	-38.75	-42.45	-46.93	-52.46	-59.47	-68.65
800	-18.29	-19.19	-20.19	-21.29	-22.52	-23.91	-25.47	-27.25	-29.30	-31.69	-34.50	-37.85	-41.93	-46.99	-53.44	-61.95
900	-16.41	-17.23	-18.13	-19.13	-20.25	-21.51	-22.93	-24.56	-26.44	-28.63	-31.21	-34.30	-38.07	-42.78	-48.82	-56.84
1000	-14.91	-15.66	-16.48	-17.41	-18.44	-19.60	-20.91	-22.42	-24.16	-26.19	-28.59	-31.48	-35.02	-39.46	-45.19	-52.86
1100	-13.68	-14.37	-15.14	-16.00	-16.96	-18.04	-19.26	-20.67	-22.30	-24.21	-26.47	-29.20	-32.56	-36.79	-42.20	-49.71
1200	-12.66	-13.31	-14.03	-14.83	-15.73	-16.74	-17.90	-19.22	-20.76	-22.57	-24.72	-27.32	-30.53	-34.61	-39.93	-47.19
1300	-11.80	-12.41	-13.09	-13.84	-14.69	-15.65	-16.75	-18.01	-19.47	-21.19	-23.25	-25.75	-28.85	-32.80	-38.01	-45.17
1400	-11.06	-11.64	-12.28	-13.00	-13.81	-14.72	-15.77	-16.97	-18.37	-20.03	-22.01	-24.43	-27.44	-31.30	-36.42	-43.56
1500	-10.43	-10.98	-11.59	-12.28	-13.05	-13.92	-14.92	-16.08	-17.43	-19.03	-20.95	-23.30	-26.24	-30.04	-35.12	-42.28

SOIL TYPE = DALHART FS1

FUEL TYPE = ELECTRICITY

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-0.38	-0.40	-0.42	-0.44	-0.46	-0.49	-0.52	-0.56	-0.60	-0.64	-0.70	-0.76	-0.84	-0.93	-1.05	-1.20
600	-0.32	-0.33	-0.35	-0.37	-0.39	-0.41	-0.44	-0.47	-0.50	-0.54	-0.59	-0.65	-0.71	-0.79	-0.90	-1.03
700	-0.27	-0.29	-0.30	-0.32	-0.34	-0.36	-0.38	-0.41	-0.44	-0.47	-0.51	-0.56	-0.62	-0.70	-0.79	-0.91
800	-0.24	-0.25	-0.27	-0.28	-0.30	-0.32	-0.34	-0.36	-0.39	-0.42	-0.46	-0.50	-0.56	-0.62	-0.71	-0.82
900	-0.22	-0.23	-0.24	-0.25	-0.27	-0.29	-0.30	-0.33	-0.35	-0.38	-0.41	-0.46	-0.51	-0.57	-0.65	-0.75
1000	-0.20	-0.21	-0.22	-0.23	-0.24	-0.26	-0.28	-0.30	-0.32	-0.35	-0.38	-0.42	-0.46	-0.52	-0.60	-0.70
1100	-0.18	-0.19	-0.20	-0.21	-0.22	-0.24	-0.26	-0.27	-0.30	-0.32	-0.35	-0.39	-0.43	-0.49	-0.56	-0.66
1200	-0.17	-0.18	-0.19	-0.20	-0.21	-0.22	-0.24	-0.26	-0.28	-0.30	-0.33	-0.36	-0.41	-0.46	-0.53	-0.63
1300	-0.16	-0.16	-0.17	-0.18	-0.19	-0.21	-0.22	-0.24	-0.26	-0.28	-0.31	-0.34	-0.38	-0.44	-0.50	-0.60
1400	-0.15	-0.15	-0.16	-0.17	-0.18	-0.20	-0.21	-0.23	-0.24	-0.27	-0.29	-0.32	-0.36	-0.42	-0.48	-0.58
1500	-0.14	-0.15	-0.15	-0.16	-0.17	-0.18	-0.20	-0.21	-0.23	-0.25	-0.28	-0.31	-0.35	-0.40	-0.47	-0.56

SOIL TYPE = DALHART FS1

FUEL TYPE = PROPANE

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-2.94	-3.08	-3.24	-3.41	-3.60	-3.81	-4.05	-4.33	-4.64	-5.00	-5.42	-5.92	-6.52	-7.25	-8.17	-9.36
600	-2.47	-2.59	-2.72	-2.87	-3.03	-3.22	-3.42	-3.65	-3.92	-4.23	-4.59	-5.02	-5.54	-6.18	-6.98	-8.03
700	-2.14	-2.24	-2.36	-2.49	-2.63	-2.79	-2.97	-3.17	-3.41	-3.68	-4.00	-4.30	-4.85	-5.42	-6.14	-7.09
800	-1.89	-1.98	-2.09	-2.20	-2.33	-2.47	-2.63	-2.82	-3.03	-3.27	-3.56	-3.91	-4.33	-4.85	-5.52	-6.40
900	-1.69	-1.78	-1.87	-1.98	-2.09	-2.22	-2.37	-2.54	-2.73	-2.96	-3.22	-3.54	-3.93	-4.42	-5.04	-5.87
1000	-1.54	-1.62	-1.70	-1.80	-1.90	-2.02	-2.16	-2.32	-2.50	-2.71	-2.95	-3.25	-3.62	-4.08	-4.67	-5.46
1100	-1.41	-1.48	-1.56	-1.65	-1.75	-1.86	-1.99	-2.14	-2.30	-2.50	-2.73	-3.02	-3.36	-3.80	-4.37	-5.13
1200	-1.31	-1.37	-1.45	-1.53	-1.62	-1.73	-1.85	-1.99	-2.14	-2.33	-2.55	-2.82	-3.15	-3.57	-4.12	-4.87
1300	-1.22	-1.28	-1.35	-1.43	-1.52	-1.62	-1.73	-1.86	-2.01	-2.19	-2.40	-2.66	-2.98	-3.39	-3.93	-4.67
1400	-1.14	-1.20	-1.27	-1.34	-1.43	-1.52	-1.63	-1.75	-1.90	-2.07	-2.27	-2.52	-2.83	-3.23	-3.76	-4.50
1500	-1.08	-1.13	-1.20	-1.27	-1.35	-1.44	-1.54	-1.66	-1.80	-1.97	-2.16	-2.41	-2.71	-3.10	-3.63	-4.37

SOIL TYPE = DALHART FS1

FUEL TYPE = DIESEL

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-4.67	-4.89	-5.14	-5.41	-5.72	-6.05	-6.44	-6.87	-7.36	-7.94	-8.60	-9.40	-10.35	-11.51	-12.98	-14.86
600	-3.93	-4.12	-4.33	-4.56	-4.82	-5.10	-5.43	-5.80	-6.22	-6.72	-7.29	-7.97	-8.80	-9.81	-11.09	-12.75
700	-3.40	-3.56	-3.75	-3.95	-4.17	-4.43	-4.71	-5.04	-5.41	-5.85	-6.36	-6.96	-7.70	-8.60	-9.75	-11.26
800	-3.00	-3.15	-3.31	-3.49	-3.69	-3.92	-4.18	-4.47	-4.81	-5.20	-5.66	-6.21	-6.88	-7.71	-8.77	-10.16
900	-2.69	-2.83	-2.97	-3.14	-3.32	-3.53	-3.76	-4.03	-4.34	-4.70	-5.12	-5.63	-6.24	-7.02	-8.01	-9.32
1000	-2.44	-2.57	-2.70	-2.85	-3.02	-3.21	-3.43	-3.68	-3.96	-4.30	-4.69	-5.16	-5.74	-6.47	-7.41	-8.67
1100	-2.24	-2.36	-2.48	-2.62	-2.78	-2.96	-3.16	-3.39	-3.66	-3.97	-4.34	-4.79	-5.34	-6.03	-6.94	-8.15
1200	-2.08	-2.18	-2.30	-2.43	-2.58	-2.75	-2.94	-3.15	-3.41	-3.70	-4.05	-4.48	-5.01	-5.68	-6.55	-7.74
1300	-1.94	-2.04	-2.15	-2.27	-2.41	-2.57	-2.75	-2.95	-3.19	-3.48	-3.81	-4.22	-4.73	-5.38	-6.23	-7.41
1400	-1.81	-1.91	-2.01	-2.13	-2.27	-2.42	-2.59	-2.78	-3.01	-3.28	-3.61	-4.01	-4.50	-5.13	-5.97	-7.14
1500	-1.71	-1.80	-1.90	-2.01	-2.14	-2.28	-2.45	-2.64	-2.86	-3.12	-3.44	-3.82	-4.30	-4.93	-5.76	-6.93

SOIL TYPE = DALHART FS1

FUEL TYPE = GASOLINE

CAPACITY (gpm)	WELL DEPTH (ft) 25	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400
500	-3.70	-3.87	-4.07	-4.28	-4.52	-4.79	-5.09	-5.44	-5.83	-6.28	-6.81	-7.44	-8.19	-9.11	-10.27	-11.77
600	-3.11	-3.26	-3.42	-3.61	-3.81	-4.04	-4.30	-4.59	-4.93	-5.32	-5.77	-6.31	-6.96	-7.77	-8.78	-10.09
700	-2.69	-2.82	-2.97	-3.13	-3.30	-3.50	-3.73	-3.99	-4.28	-4.63	-5.03	-5.51	-6.09	-6.81	7.72	-8.91
800	-2.37	-2.49	-2.62	-2.76	-2.92	-3.10	-3.31	-3.54	-3.88	-4.11	-4.48	-4.91	-5.44	-6.10	-6.94	-8.04
900	-2.13	-2.24	-2.35	-2.48	-2.63	-2.79	-2.98	-3.19	-3.43	-3.72	-4.05	-4.45	-4.94	-5.55	-6.34	-7.38
1000	-1.94	-2.03	-2.14	-2.26	-2.39	-2.54	-2.72	-2.91	-3.14	-3.40	-3.71	-4.09	-4.55	-5.12	-5.87	-6.86
1100	-1.78	-1.87	-1.97	-2.08	-2.20	-2.34	-2.50	-2.68	-2.90	-3.14	-3.44	-3.79	-4.23	-4.78	-5.49	-6.45
1200	-1.64	-1.73	-1.82	-1.93	-2.04	-2.17	-2.32	-2.50	-2.70	-2.93	-3.21	-3.55	-3.96	-4.49	-5.18	-6.13
1300	-1.53	-1.61	-1.70	-1.80	-1.91	-2.03	-2.17	-2.34	-2.53	-2.75	-3.02	-3.34	-3.75	-4.26	-4.93	-5.86
1400	-1.44	-1.51	-1.60	-1.69	-1.79	-1.91	-2.05	-2.20	-2.39	-2.60	-2.86	-3.17	-3.56	-4.06	-4.73	-5.66
1500	-1.35	-1.43	-1.50	-1.59	-1.69	-1.81	-1.94	-2.09	-2.26	-2.47	2.72	-3.03	-3.41	-3.90	-4.56	-5.49

ECONOMICS OF REPLACING OPEN IRRIGATION DITCHES WITH GATED PIPE

by

KENNETH GREGG BUTLER

B.S., Kansas State University, 1980

AN ABSTRACT OF A MASTER'S REPORT

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In 1977, Kansas had 3.16 million acres of irrigated farm land. Of this total, 3.07 million acres were served from groundwater resources leaving only 90,000 acres irrigated by surface water resources. From 1974 to 1977 energy costs to pump the water increased from $570 million to more than $1 billion, yet the increased costs failed to slow the growth of pump irrigation. Of the 3.16 million acres irrigated in 1977, 2.27 million acres were irrigated by surface methods with gated pipe and open ditch being the most common.

With diminishing groundwater supplies in the midwestern United States and rapidly increasing energy costs, the efficient use of water for irrigation is becoming more important every day.

Irrigation supply ditches are one source of water losses in the great plains region. Large losses can occur in open ditches due to seepage and evaporation--seepage losses are much greater than evaporation losses. Seepage and evaporation water losses can be eliminated by replacing the open ditch with pipe (usually gated aluminum or plastic).

The purpose of this paper was to examine the economics of replacing open ditches with gated pipe and to present the results in a manner such that irrigators could understand and utilize.

The first approach to this problem was to define 13 factors that determine the cost of pumping the wasted water in the open ditch systems. A breakeven energy cost equation was used to allow irrigator's to see realistic variables plugged into it and the outcoming results. Tables and graphs presented these results, and the use of the equation by irrigator's was promoted. In some cases it was cost-effective to switch to gated pipe and in other situations it was not. Soil type was found to be the dominant variable.

In the second approach, the cost of water loss based on its potential productivity was examined. Five crops were examined and the number of acres of each crop which could be irrigated sufficiently with the wasted water from a 2600 foot ditch was computed. Next, the expected yield, gross yield from acreage, gross income, total annual variable crop production costs, annual net income to pipe, annual net income to pipe per foot, capital recovery factor, and affordable purchase price of pipe per foot were calculated. The results were significant in that it was economical to purchase pipe for two of the three soils analyzed.

These results gave strength to the idea of switching from an open ditch to gated pipe. It could be cost-effective to do it now and if not, it may be in the future as energy prices increase. Even if it is not cost-effective to make the switch, greater profits could be realized by conserving the wasted water and applying it to more acres as was illustrated in the cost of water loss based on potential productivity section.