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A CAPITAL COST COMPARISON OF COMMERCIAL GROUND-SOURCE HEAT PUMP SYSTEMS

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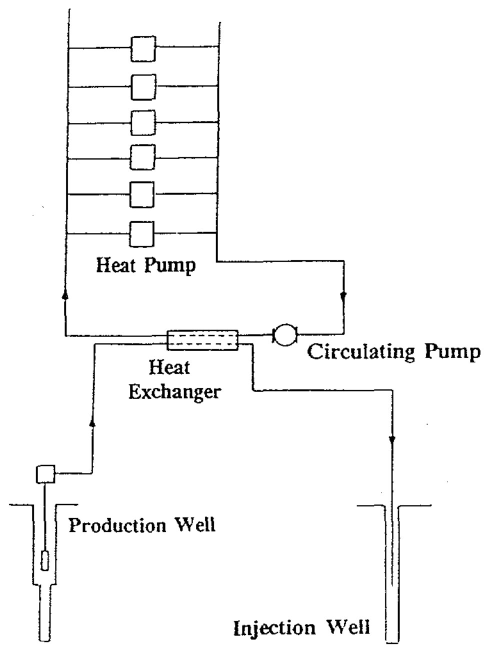
A CAPITAL COST COMPARISON OF COMMERCIAL GROUND-SOURCE HEAT PUMP SYSTEMS

INTRODUCTION

Unitary ground-source heat pump systems for commercial buildings can be installed in a variety of configurations. The oldest and, until recently, most widely used approach was the groundwater system. In this design (Figure 1), groundwater from a well or wells is delivered to a heat exchanger installed in the heat pump loop. After passing through the heat exchanger (where it absorbs heat from or delivers heat to the loop), the groundwater is disposed of on the surface or in an injection well. The use of an injection well is desirable in order to conserve the groundwater resource.

Figure 1
Groundwater Heat Pump System



A second and increasingly popular design is the ground-coupled heat pump system. In this approach (Figure 2), a closed loop of buried piping is connected to the building loop. For most larger commercial applications, the buried piping is installed in a grid of vertical boreholes 100 to 300 ft deep. Heat pump loop water is circulated through the buried piping network absorbing heat from or delivering heat to the soil. The quantity of buried piping varies with climate and building characteristics, but is generally in the range of 150 to 250 ft (of borehole) per ton of system capacity. Borehole length requirements are almost always dictated by heat rejection (cooling mode) duty for commercial buildings.

Figure 2
Ground-Coupled Heat Pump System

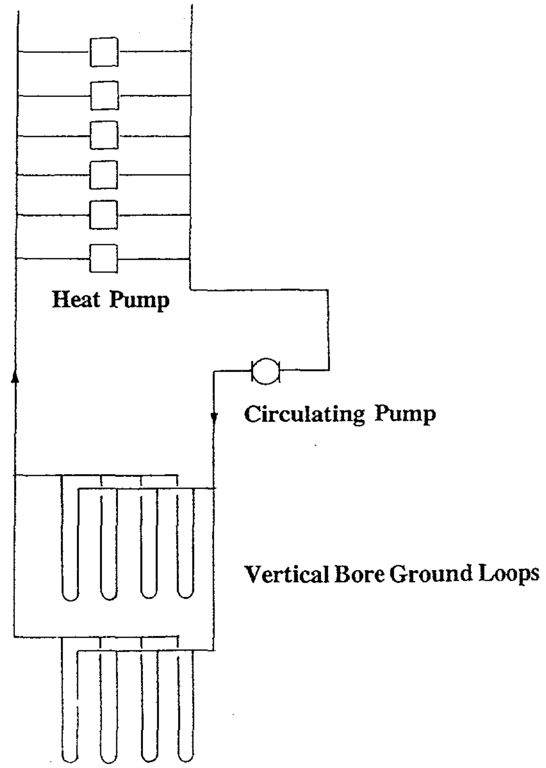
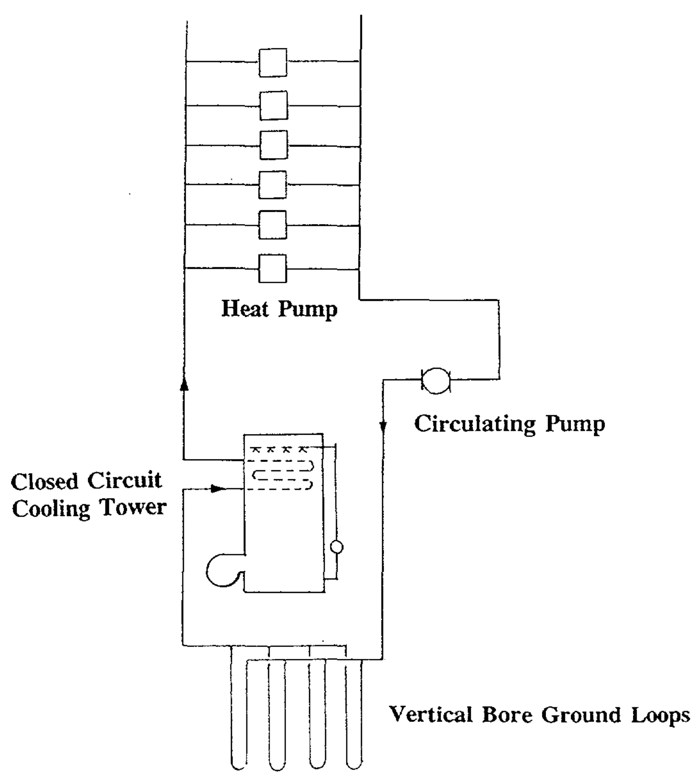


Figure 3
Hybrid Ground-Coupled Heat Pump System



A third design for ground-source system in commercial buildings is the "hybrid" system. This approach (Figure 3) may also be considered a variation of the ground-coupled design. Due to the high cost associated with installing a ground loop to meet the peak cooling load, the hybrid system includes a cooling tower. The use of the tower allows the designer to size the ground loop for the heating load and use it in combination with the tower to meet the peak cooling load. The tower preserves some of the energy efficiency of the system, but reduces the capital cost associated with the ground loop installation.

In addition to the three designs discussed above, ground source systems can also be installed using lake water, standing column wells and horizontal ground coupled approaches. This report focuses on the three former schemes due to their wider use and broad potential application.

The purpose of the report is to compare capital costs associated with the three designs. Specifically, the costs considered are those associated with the heat source/heat sink or ground source portion of the system. In order to standardize the heat rejection over the three designs, it was assumed that the heat pump loop would operate at a temperature range of 85° (to the heat pumps) to 95° (from the heat pumps) under peak conditions. The assumption of constant loop temperature conditions for all three permits an apples-to-apples comparison of the alternatives.

The following items are included in the costs calculated in this report.

Groundwater system:

- Production well (or wells)
- Production well pump test
- Production well pump
- Well pump variable speed drive
- Buried piping (wells to building)
- Heat exchanger
- Heat exchanger controls
- Injection well
- Injection well test
- 15% contingency factor

Ground coupled system:

- Vertical borehole
- Loop installation
- Header piping and installation

Hybrid system:

- Vertical boreholes
- Loop installation
- Header piping and installation
- Closed circuit cooling tower

- Tower pad
- Tower piping
- 15% contingency (on tower and accessories)

Commercial building is a term which can cover a very broad spectrum of sizes from a few hundred square feet to several million square feet. The range selected for this report includes system sizes from 50 to 500 tons. Using an average value of 300 ft^2 per ton, this translates into a building area range of 15,000 to 150,000 ft^2. Buildings in this size range comprise the bulk of the commercial building stock in the United States.

In order for the results to be as broadly applicable as possible, cost calculations were made for a wide variety of soil (or groundwater) temperatures, well depths (groundwater), loop lengths (ground coupled) and tower/loop ratios (hybrid system).

It is common in the ground-source heat pump industry to refer to costs for the ground source portion of the system on a cost per ton basis. In keeping with this practice, most cost data presented for this report is expressed in terms of cost per ton. It is important to note, however, that the cost per ton refers to the actual load imposed on the ground source portion of the system. This is not the same as the installed capacity of the equipment. Due to load diversity, the peak load imposed upon the heat rejection equipment is always less than the total installed capacity. The load used for cost calculations in this report is frequently referred to by engineers as the block load.

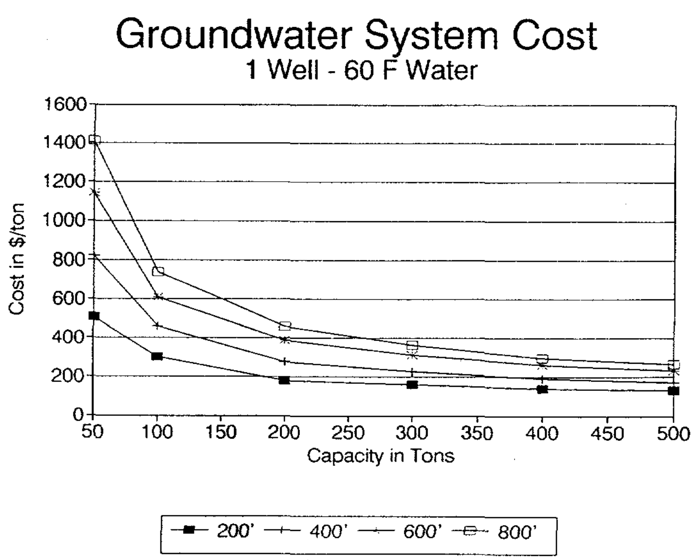
SUMMARY

The purpose of this report is to compare the capital costs associated with installation of three different ground-source heat pump systems: groundwater, ground-coupled and hybrid (ground-coupled with tower) over a size range of 50 to 500 tons. The tonnage range refers to building block load rather than installed capacity. The basis for all calculations is a building loop temperature during the peak cooling load of 85°F supply water (to the heat pump) and 95°F return water (from the heat pump). Costs shown address only the ground source portion of the system.

Costs were developed for three groundwater/soil temperatures 50°, 60° and 70°F representing northern, central and southern climates. For brevity, only the results for the 60° cases are presented in this summary.

Figure 4 presents the results for the 60°F groundwater case assuming the use of a single production/injection well pair to serve the system. The four curves shown indicate costs (in $/ton) for four different groundwater well depths: 200, 400, 600 and 800 feet. In all cases, the values shown include costs for the production wells, well flow testing, production well pump, pump variable-speed drive, buried piping for transport of the groundwater to the building, heat exchanger to isolate the groundwater from the building loop, heat exchanger controls, injection well, injection well flow testing and a 15% contingency factor. As indicated, the depth requirement for the wells has a substantial impact upon the installed cost. In addition, the unit cost for small systems (50 - 100 tons) is often higher by a factor of 3 compared to costs for larger systems (300 - 500 tons).

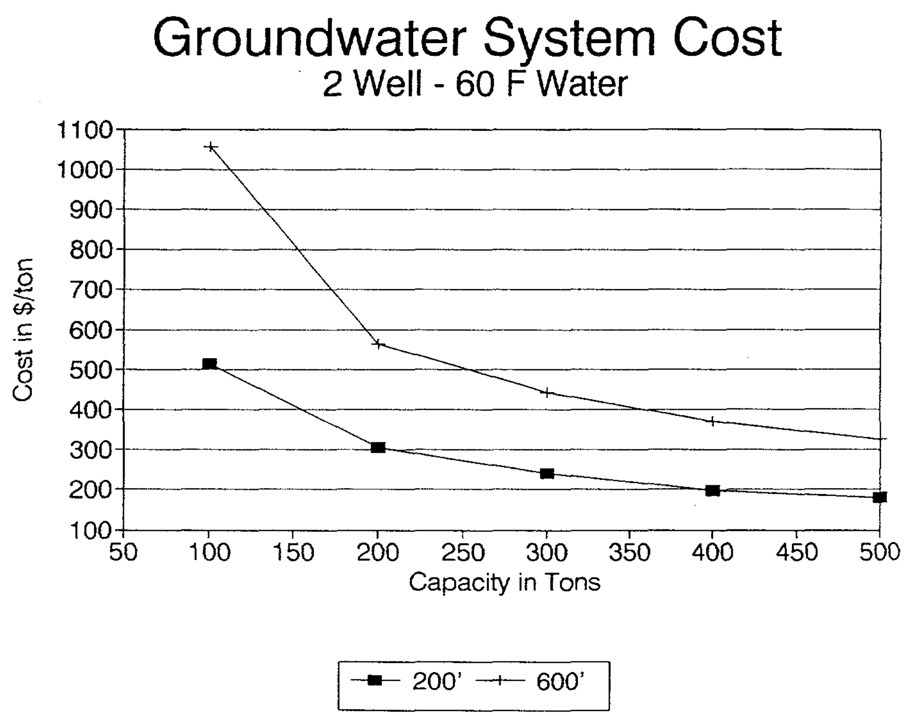
Figure 4



In many cases, a single production/injection well pair may not be capable of producing (or injecting) the required system flow rate. To address this situation, costs were calculated for systems using 2 production wells and 2 injection wells. In addition to the wells, adjustments were also made in well pump, piping, and testing costs to accommodate the installation of the additional wells. Figure 5 presents these costs for 200 and 600 foot well depths and system sizes of 100 to 500 tons.

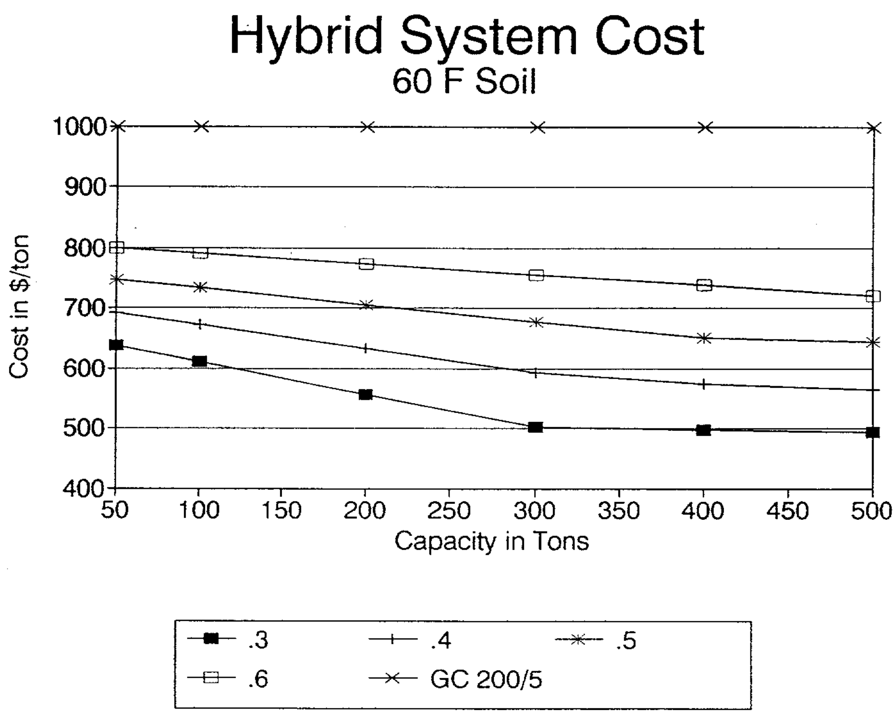
For ground-coupled systems actual project costs rather than calculations were used. Costs for these systems are a function of two values--the number of feet of borehole necessary per ton of heat rejection and the cost per foot for completing the vertical bore and installing the piping. For purposes of this report, the values of 150 feet per ton for 50°F soil, 200 feet per ton for 60°F soil and 250 feet per ton for 70°F soil have been used. To arrive at a cost per ton, a value of $5 per foot of bore has been used. Although some recent projects have been the beneficiary of costs as low as $3.75 per foot and one as low as $3 per foot, many areas of the country are still reporting costs of as much as $15 per foot.

Figure 5



Hybrid systems include both a ground loop and a cooling tower. The ground loop is sized to meet the heating load and it along with the tower is used to meet the cooling heat rejection load. As a result, hybrid system costs are a combination of ground loop costs and cooling tower costs. Using the $5 per foot value for the hybrid ground loop portion and vendor quotes for the cooling tower, Figure 6 shows the cost per ton for the hybrid system based on 60°F soil temperature. Hybrid system costs were also developed for 50° and 70°F soil. The four curves shown for the hybrid system reflect costs for different ratios of heating loop lengths versus cooling loop lengths. As indicated, hybrid systems enjoy more favorable economics as the heating ground loop length decreases as percentage of the cooling ground loop length requirement. This is because the cost per ton of the cooling tower is less than the cost per ton of the ground loop.

Figure 6



Generally, the hybrid system is attractive in situations where ground loop costs per ton are high; and where the heating loop length requirement is low relative to the cooling loop length requirement.

Figure 7 presents a comparison of the three types of systems for 60° soil. The ground-coupled system cost line is based upon $5 per foot and 200 ft per ton ($1000 per ton). The two hybrid system curves are based upon loop length ratios (heating ÷ cooling) of .30 and .40 evaluated in this report. These are the most favorable conditions for hybrid systems. The two groundwater curves are based upon 200 ft wells and 1 production/injection well pair (lower curve) and 2 production/injection well pairs (upper curve). Again, these are the most favorable conditions calculated for groundwater systems in this report. It is clear that, based on these conditions, the groundwater system enjoys substantial capital cost advantage over the remaining two systems over the entire range of capacity covered.

Figure 7

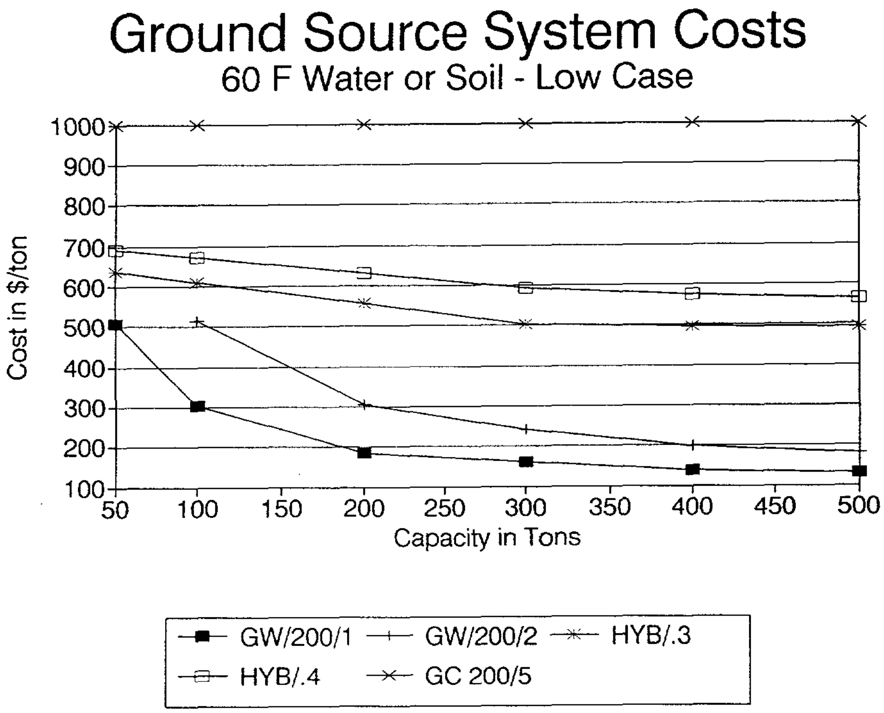
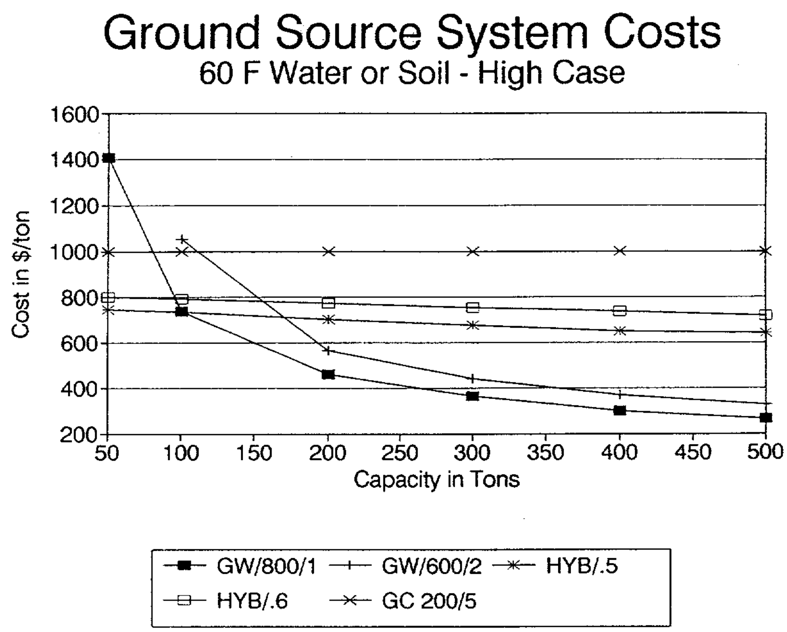


Figure 8 presents additional data for the 60°F soil case. Again, the ground-coupled line is based on 200 ft per ton and $5 per foot. The two hybrid system curves are based upon loop length ratios of .50 (lower) and .60 (upper). These are the least favorable conditions for the hybrid systems covered in this report. The two curves for the groundwater system are based upon a single production/injection well pair at 800 foot depth (lower curve) and 2 production/injection well pairs at a 600 foot depth. These are the least favorable conditions for the groundwater system covered in this report.

As indicated at system capacities of 100 - 175 tons and above, the groundwater system has the capital cost advantage over hybrid and ground-coupled systems. Below this range the hybrid system is the most attractive. It is only under conditions of less than 100 tons with well depths of 800 feet, that the groundwater system capital cost exceeds that of the ground-coupled system.

Figure 8



This report addresses only system capital cost. In the process of system selection, other issues should be considered as well. These would include operating costs such as electricity for pumps and fans, water treatment costs (tower) and regulatory issues with respect to groundwater. As a result, system capital cost provides only a portion of the information required for informed decision making.

GROUNDWATER SYSTEMS

Background

For groundwater systems, 10 individual cost areas were considered in this evaluation. These areas include the following:

- Production well (or wells)
- Production well pump test
- Production well pump
- Well pump variable-speed drive
- Buried piping (wells to building)
- Heat exchanger
- Heat exchanger controls
- Injection well (or wells)
- Injection well pump test
- 15% contingency

Injection well pumps were not included due to assumptions regarding static and pumping water levels for the wells. This issue is discussed in more detail under the injection well section.

The items selected include several which have not commonly been incorporated in existing groundwater heat pump systems, such as injection wells, variable-speed drives and heat exchangers. Although these items increase the capital cost of the groundwater system, they are considered essential to a design which will provide long-term mechanical reliability, energy efficiency and groundwater aquifer conservation (ASHRAE, 1994)(Rafferty, 1992)(Hatter, 1992).

Costs for groundwater systems were calculated for three different water temperatures: 50°, 60° and 70°F. These temperatures roughly approximate those characteristic of a northern, central and southern U.S. climates respectively.

The following sections briefly describe the individual cost areas and the specific items included. Additional details on costs appear in the Appendix.

Production Well

Well cost is a function of depth, diameter and drilling conditions. For purposes of this report, well costs were calculated for 4 different depths 200 ft, 400 ft, 600 ft, and 800 ft. Well size was based upon heat pump system flow requirements and the following table:

Table 1
Casing Size Requirements (Culver, 1991)

Flow	Pump Size	In. Casing Size
<100	4	6
100 to 175	5	8
175 to 350	6	10
350 to 700	8	12

Based on a building loop temperature range of 85 to 95°F (during the peak cooling load), the following flow requirements were calculated.

Table 2
Groundwater Flow Requirement (gpm)

System Capacity Tons	Water Temperature		
	50°	60°	70°
50	37.5	50	75
100	75	100	150
200	150	200	300
300	225	300	450
400	300	400	600
500	375	500	750

For 200 and 400 foot wells, the cost of the well was determined assuming that the casing size requirement in the table above was carried to 200 ft depth with 8 in. casing below that level. For 600 and 800 foot wells, the casing size in the table was extended to 400 feet with 8 in. casing to total depth.

Cost data for wells was drawn from a number of sources including a survey by the Geo-Heat Center of western drilling costs, a national survey by Groundwater Age magazine and data from the National Groundwater Association. Using an average of all of this data (see appendix), a value of $3.08 per inch of diameter per foot of depth resulted.

Production well costs for this report were, therefore, based upon a value of $3.00 per inch of diameter per foot of depth. Using the results of the Geo-Heat Center survey, an increase of 15% was applied to drilling costs below 600 feet.

Figure 9 presents the basic well cost data used in the study.

Figure 9

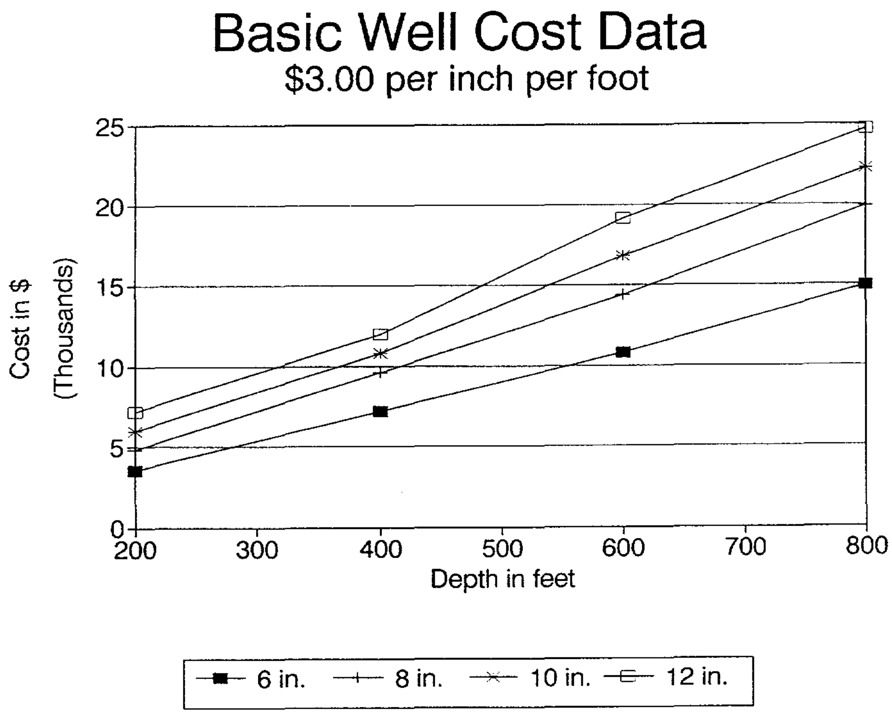


Figure 10 presents this cost data for 60°F water on a cost per ton basis. Costs for 50° and 70°F water were also calculated. These appear in the Appendix and are also incorporated into the summary figures at the end of this section.

The data above is based on a single production/injection pair well serving the system. In many cases, a single production/injection well pair may not be capable of supplying (or disposing of) the required flow rate. This is particularly true at the higher end of the capacity range evaluated in this report. In these cases, it may be necessary to construct two production wells to accommodate the required flow requirements. Figure 11 presents cost data on a per ton basis for two production wells (and two injection wells) based on 60°F water flow requirements.

All systems in this report include injection wells. References in the text and on figures to "1 well", refers to 1 production and 1 injection well serving the system. References to "2 wells" means 2 production and 2 injection wells per system.

Figure 10

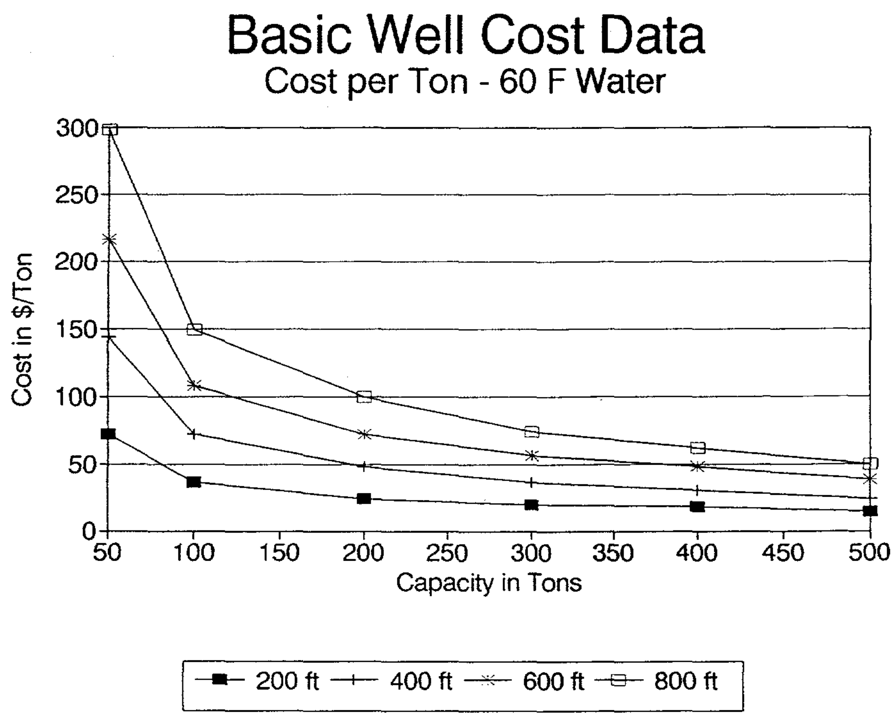
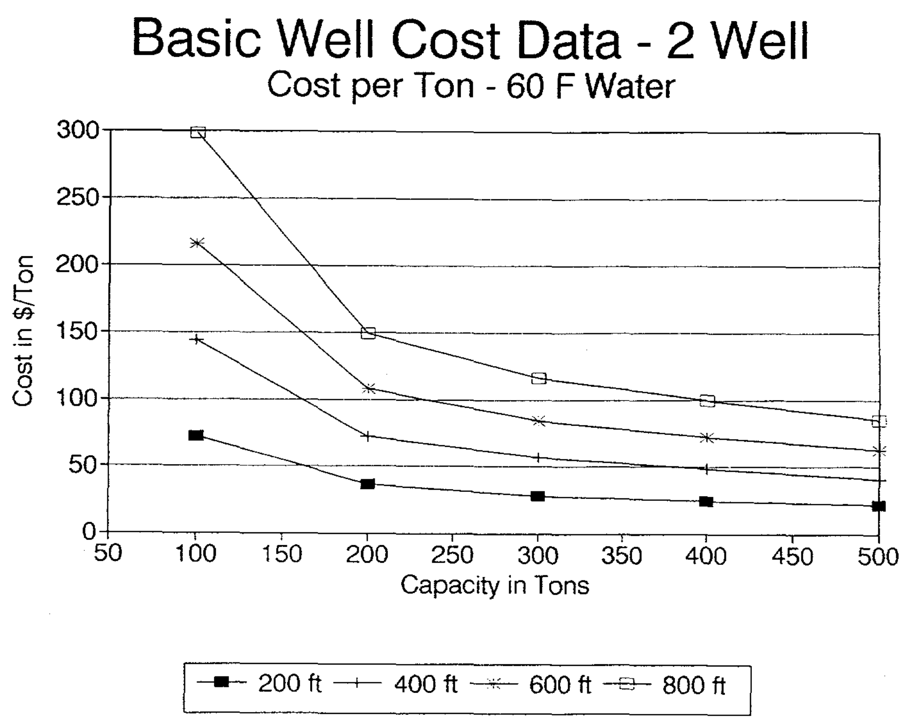


Figure 11

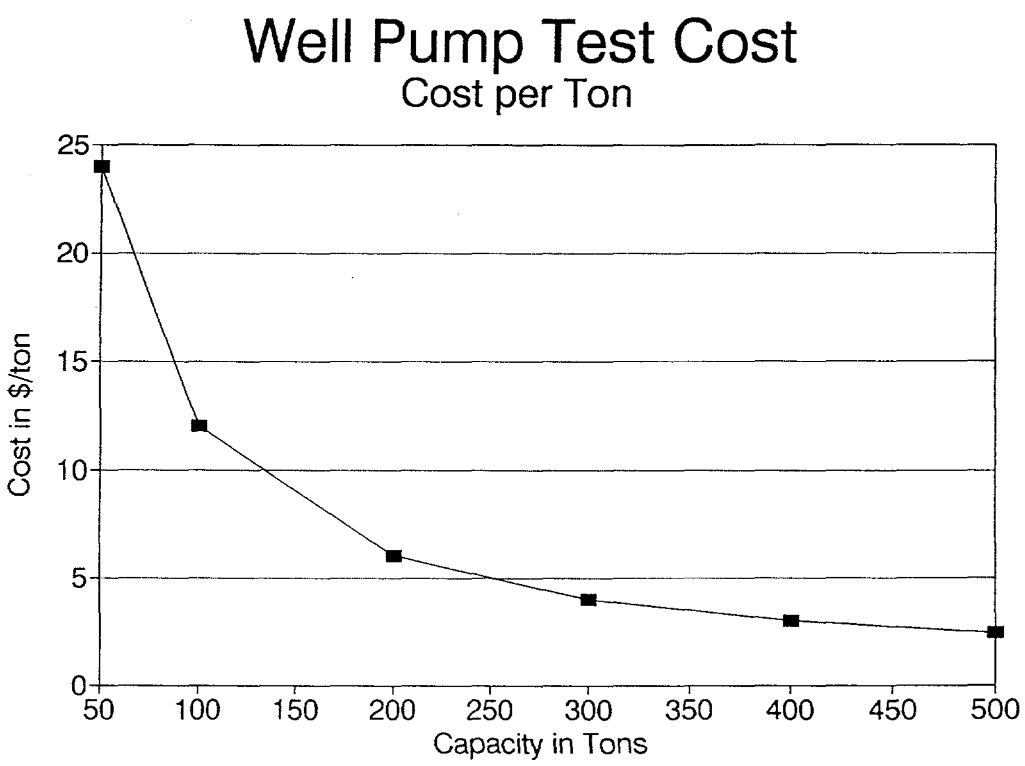


Well Flow Testing

Testing of wells subsequent to completion is normally practiced in larger applications. The pump test provides data on the well's productivity and depending upon how it is conducted, information on the reservoir from which the water is produced. Costs for this report were based on local southern Oregon/northern California values. These rates are $25/hr for the duration of the test. Total cost assumed that two 8-hour tests would be employed over a 48-hour period resulting in a pump test cost of $1200 per well.

Figure 12 presents these costs for both single production well and two production well systems on a cost per ton basis. The cost of well testing is independent of water temperature.

Figure 12



Production Well Pump

The cost of the production well pump is determined by the type of pump used (submersible or lineshaft), the flow and head required and the depth at which the pump is set.

For this report, flow was a function of the well water temperature (50°, 60°, 70°) and the capacity of the system to be served (in tons). Pumping level was assumed to be 120 ft for 200 and 400 ft wells, and 270 ft for 600 and 800 feet wells. Surface pressure requirements of 50 feet were added to arrive at total pump heads of 170 ft (200 ft/400 ft wells) and 320 ft (600 ft/800 ft wells). Pump setting depth was assumed to be 150 ft for 200 and 400 ft wells, and 300 ft for 600 and 800 ft wells.

In all cases, cost was based upon the use of submersible type pumps. In the size range necessary for systems covered here submersible pumps offer a significant cost advantage over lineshaft type pumps.

Individual cost items included were the pump and motor assembly, pump column, wire and installation. Actual cost values appear in the appendix. Figure 13 presents the basic pump (installed) costs indexed to horsepower used in this report. Figure 14 presents the data for 60°F water as a function of system capacity for both single and 2-well systems. Similar data was also developed for 50° and 70°F water. These values appear in the Appendix and are incorporated in the summary figures at the end of this section.

Figure 13

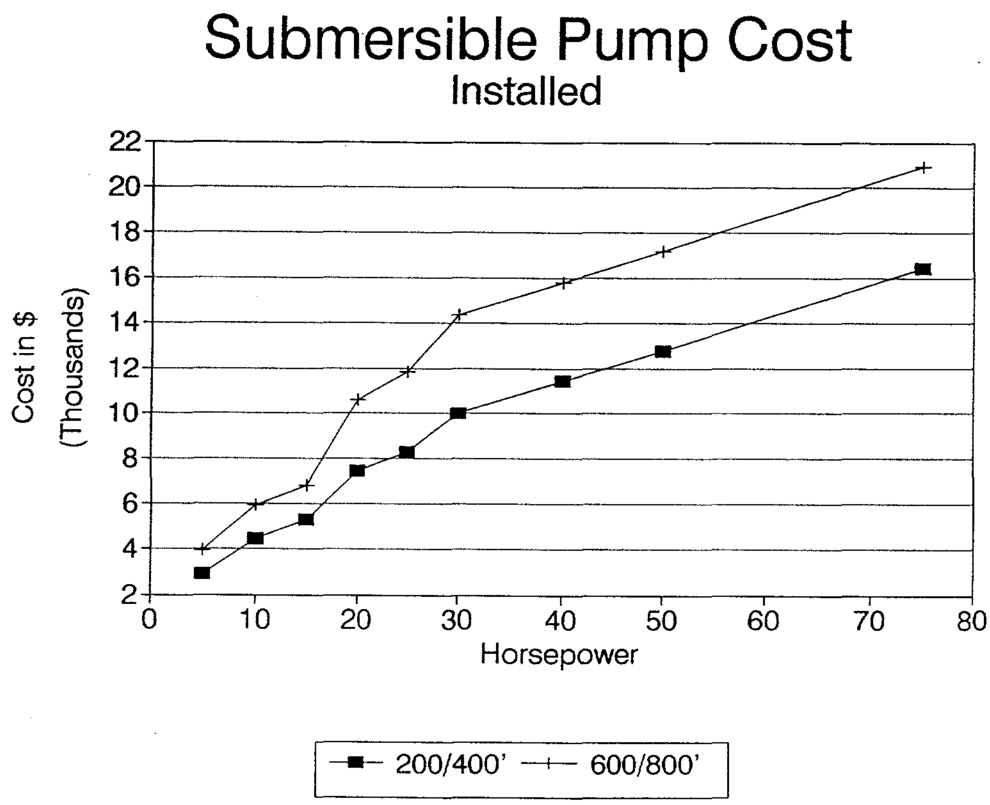
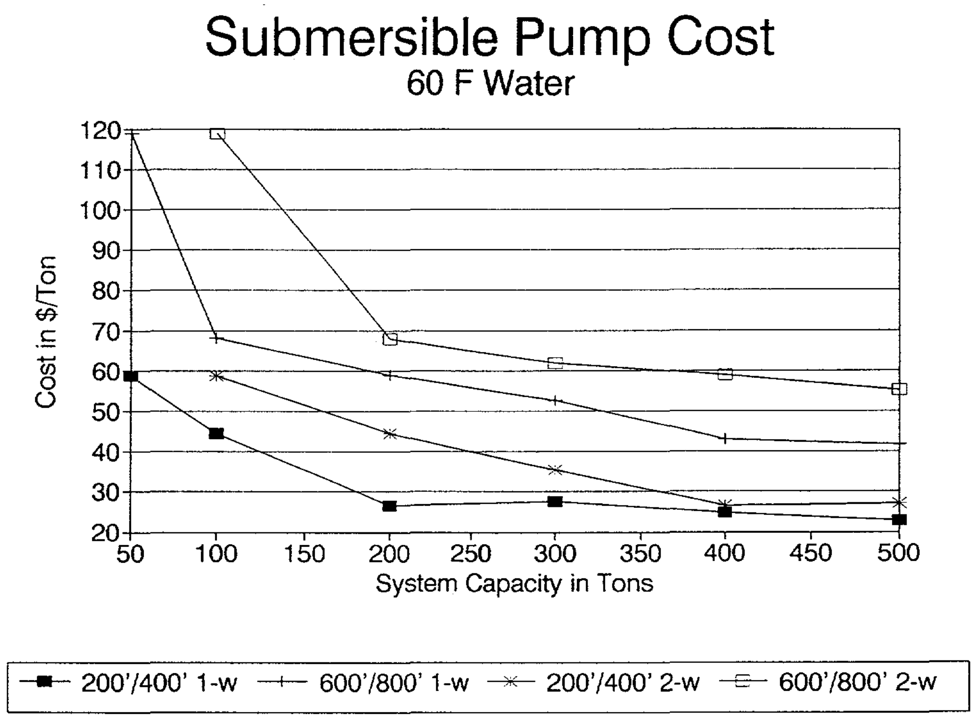


Figure 14



Variable-Frequency Drive

There is a variety of methods currently in use to control the output of a production well pump. These include no control, throttling, fluid couplings and variable-frequency drive. Of these, the variable-frequency drive is the most energy efficient and the method selected for purposes of this study.

The cost of the drive is largely a function of the horsepower of the motor which it will be used to control. Figure 15 presents the basic costs used for this report as a function of horsepower. Costs per ton for the 60°F water case appear in Figure 16. These values are based upon list price data for variable-frequency drives plus installation cost. Similar values were calculated for 50° and 70°F water. These figures appear in the Appendix and are incorporated in to the summary figures at the end of this section.

Costs for the 2-well system are lower than the single well system based on the use of a drive on only one of the two well pumps.

Figure 15

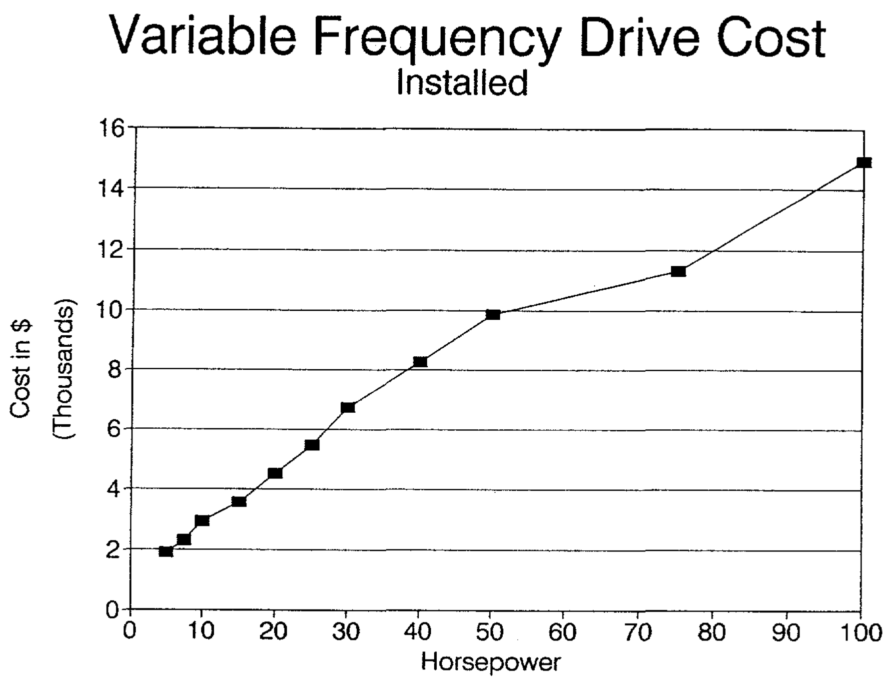
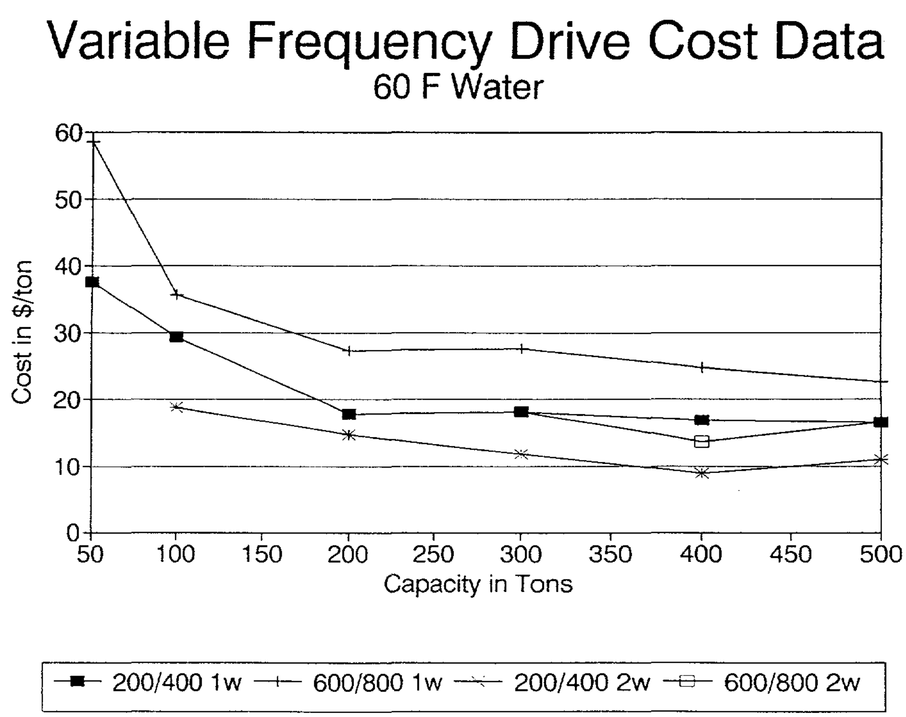


Figure 16



Buried Piping

Piping is necessary to transfer the groundwater from the production well to the building and from the building to the injection well. For purposes of this report, the use of direct buried class 160 PVC pipe was assumed. Cost items included the pipe, installation, trenching, bedding and backfilling. Table 3 presents the basic cost data for the piping on a per foot basis.

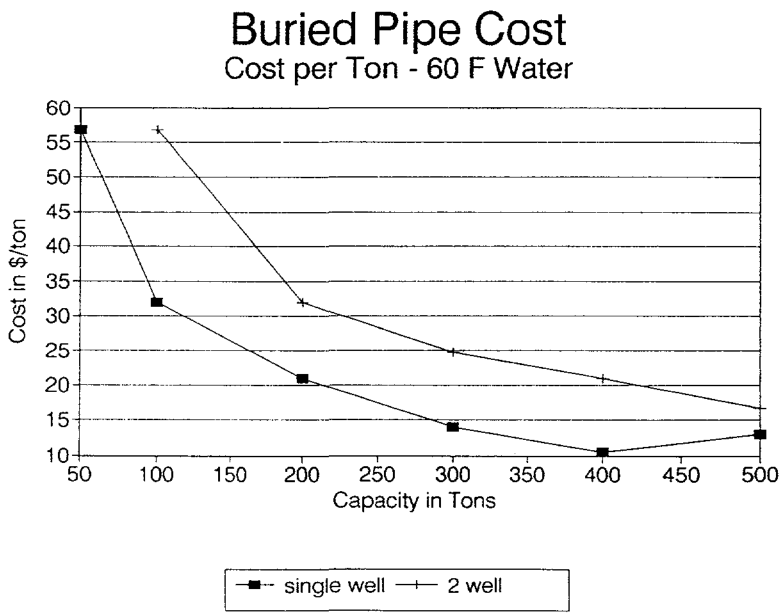
Table 3
Basic Buried Piping Cost Data (Means, 1993)

Size	Cost/ft (installed)
3	9.47
4	10.64
6	14.04
8	21.74

For the single production/injection well case 300 feet of production piping and 300 feet of injection well piping were included. For the 2-production/injection well case, these values were doubled.

Figure 17 presents the buried piping cost data for the 60°F water temperature on a cost per ton basis. Similar figures were also calculated for 50° and 70°F water. These values appear in the Appendix and are incorporated in to the summary figures at the end of this section.

Figure 17



Heat Exchanger

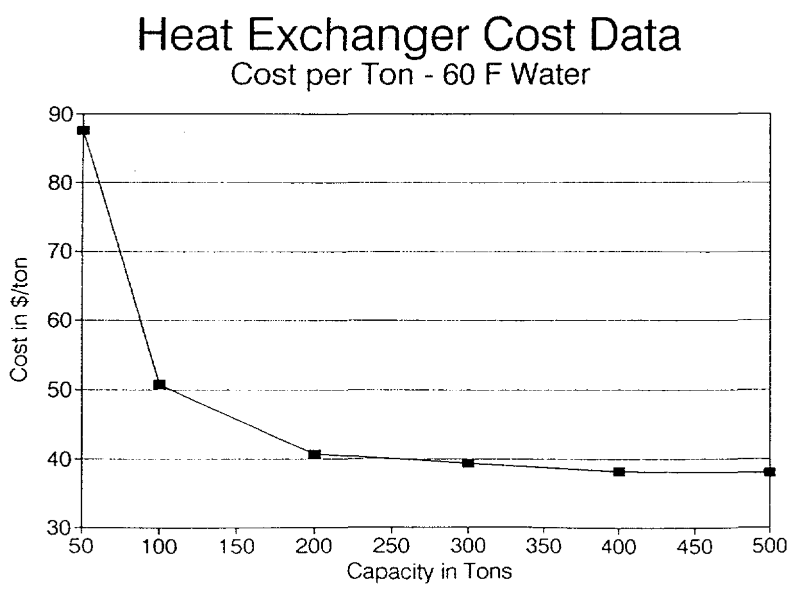
Early groundwater systems frequently circulated groundwater directly to the heat pump units. Many small residential systems still employ this design. For large commercial and industrial systems, however, it is prudent to isolate the building loop from the groundwater with a heat exchanger. Costs in this report are based on the use of plate-and-frame exchangers with 316 stainless steel plates and nitrile rubber gaskets. The heat exchanger sizing was based on the assumption of a building loop operating at 95° to 85° in the peak cooling condition. A 5° approach was assumed.

These values resulted in flow requirements of 0.75 gpm/ton, 1.0 gpm/ton and 1.5 gpm/ton for the three basic groundwater temperatures of 50°, 60° and 70°F. These unit flow rates were used as the basis for equipment sizing throughout this report.

Plate heat exchanger sizing is generally done by the vendor and no catalog procedures are available. To develop cost values for this report, required heat transfer area was calculated based upon overall heat transfer coefficient of 1000 Btu/hr•ft^2•°F and the calculated LMTD. The resulting areas was then converted to a cost using data from previous vendor quotes and data from Rafferty, 1991.

Costs per ton for the 60°F groundwater temperature case appear in Figure 18. These values include installation labor and a 15% overhead and profit factor. Heat exchanger cost is independent of the number of production wells. Cost for 50° and 70°F were also calculated and appear in the Appendix. These values are incorporated into the summary figures at the end of this section.

Figure 18

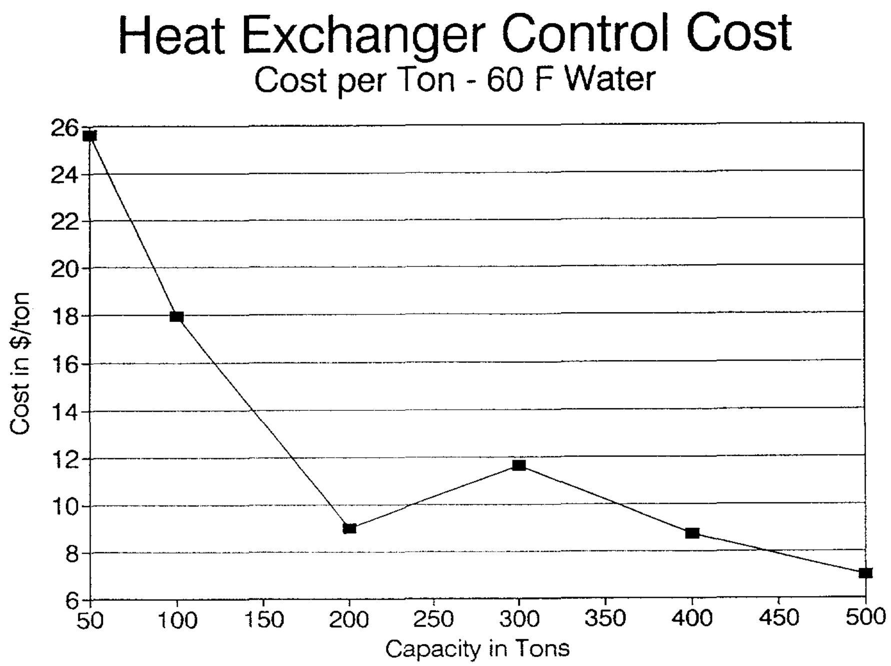


Heat Exchanger Controls

Costs for controls assume the use of a 2-way throttling valve at the heat exchanger under the control of a dual set point controller (heating mode - cooling mode). The valve would serve to throttle the flow of groundwater in response to loop temperature. The well pump variable-speed drive would respond to pressure changes in the production line to adjust groundwater flow accordingly.

Control costs as a function of system capacity at 60°F appear in Figure 19. These costs are independent of the number of production wells. Cost for 50° and 70°F groundwater were also calculated and appear in the Appendix. These values are incorporated into the summary figures at the end of this section.

Figure 19



Injection Well

Injection well cost was based upon a value of $4.00 per inch of diameter per foot of depth. This incorporates a 33% increase over the unit value used for the production well costs. The additional cost recognizes the fact that while actual drilling of the well may be the same as production wells, completion and siting may be more expensive. All injection wells were assumed to be 8 in. diameter (casing) and completed to a depth equal to the production well for the particular case in question.

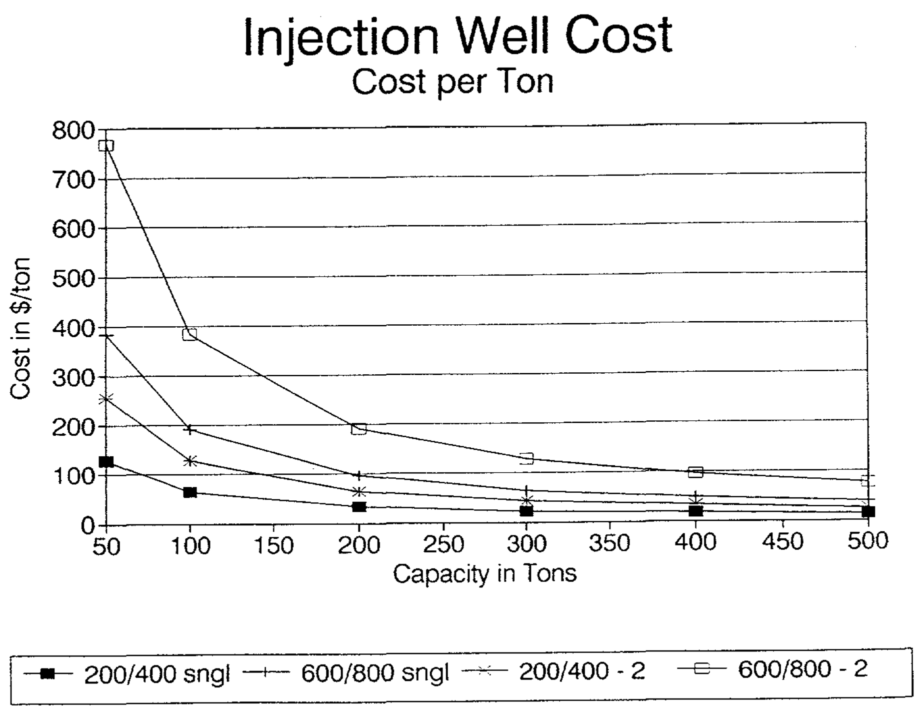
Injection pumps were not included in the cost estimate for the groundwater system due to the assumptions regarding well static and pumping levels. Production well pump sizing was based upon pump setting depths of 150 ft for 200 and 400 ft wells, and 300 ft for 600 and 800 ft wells. Static water levels were assumed to be 90 ft and 220 ft, and pumping water levels 120 ft and 270 ft respectively. Based on these assumptions even with injection well performance at only 33% of production wells, no injection pump would be required.

Table 4 presents the basic injection well cost data employed in this report. Figure 20 presents this data for the 60°F case indexed to system capacity in tons.

Table 4
Injection Well Cost Data - 8 Inch

Depth (ft)	Cost
200	$ 6,400
400	12,800
600	19,200
800	26,560

Figure 20



Injection Well Flow Testing

Costs for pump testing of the injection well were based on the same values as for the production wells. Cost data is presented in Figure 12 under Production Well Testing.

Contingency Factor

A 15% contingency factor was added to the subtotal of the other nine cost items to allow miscellaneous electrical and mechanical items not directly addressed in the above cost areas. This contingency is incorporated into the summary figures below.

Summary of Results

Figure 21 presents a summary of the cost data for 50°F water and single production/injection well pairs for 200 through 800 foot well depths. The values shown include all of the above discussed cost areas. Figures 22 and 23 present the same data from 60° and 70°F water temperatures.

Figure 21

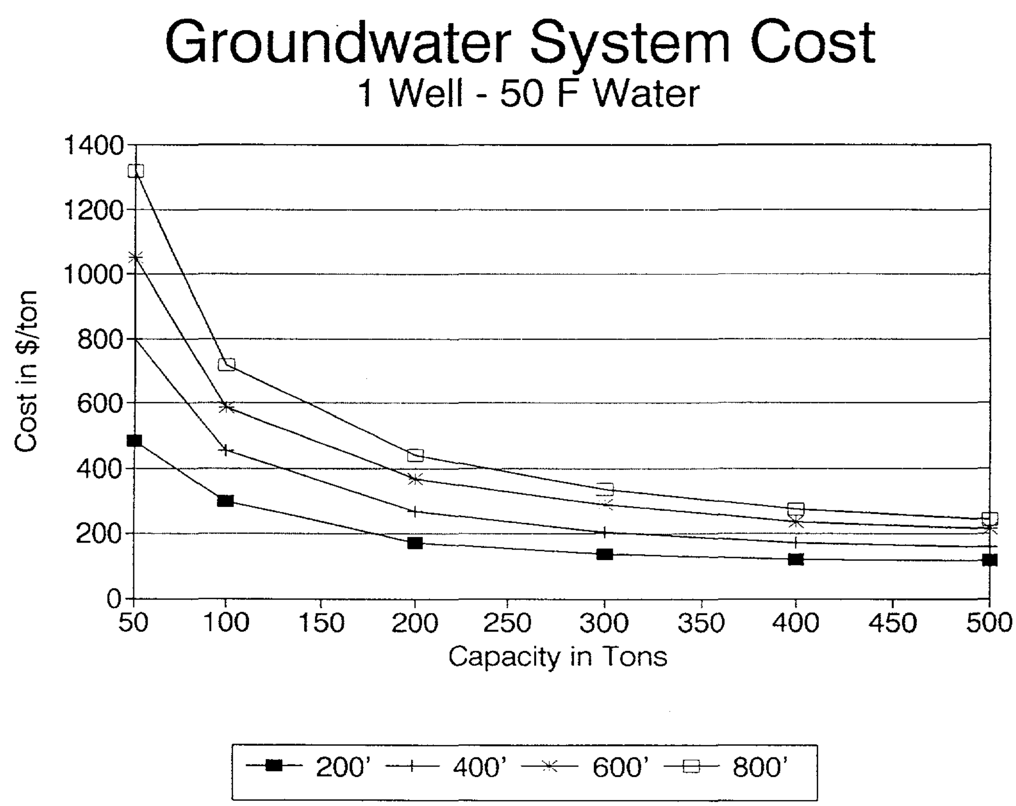


Figure 22

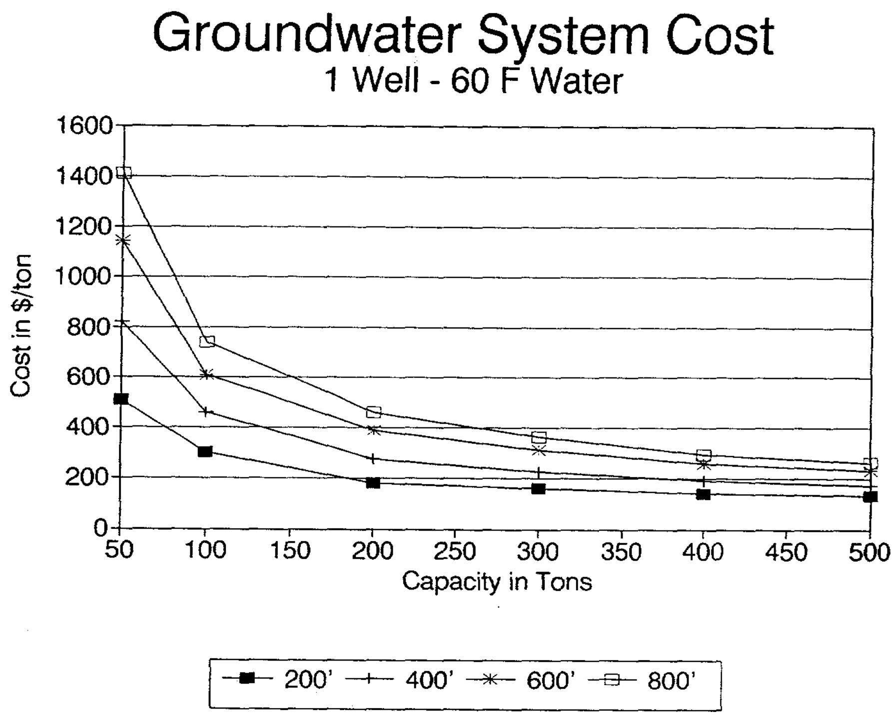


Figure 23

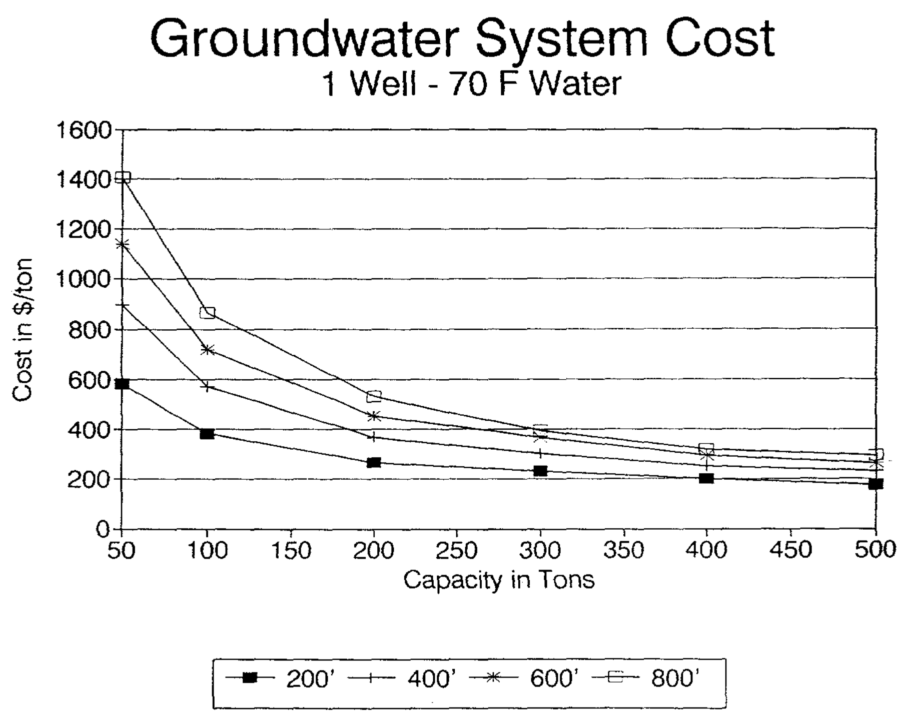


Figure 24 presents a summary of the cost data for 50°F water with two production and two injection wells for 200 and 600 foot well depths. Figures 25 and 26 present the same data for 60° and 70°F water temperatures.

Figure 24

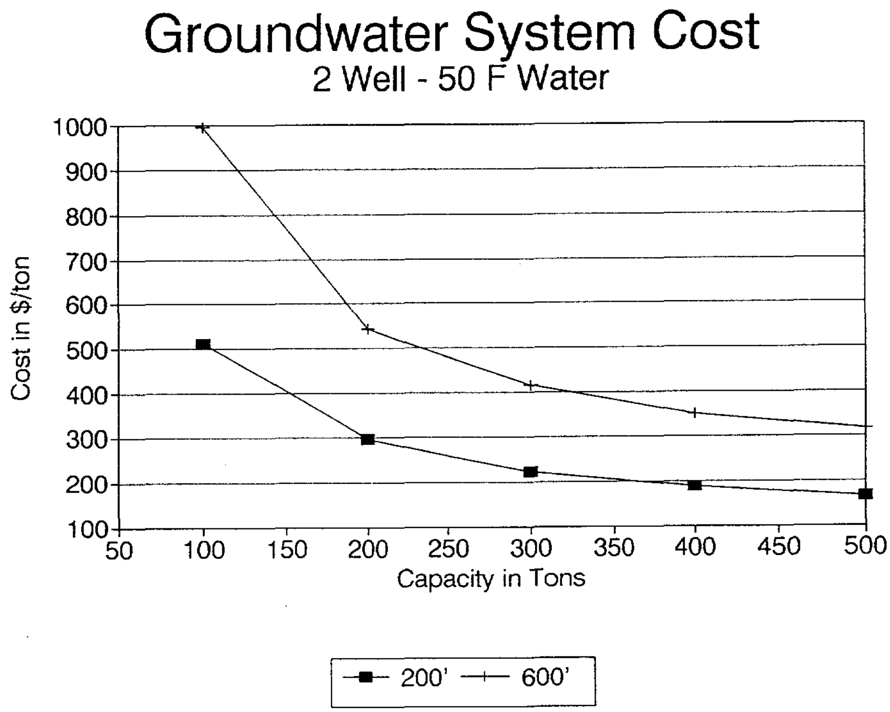


Figure 25

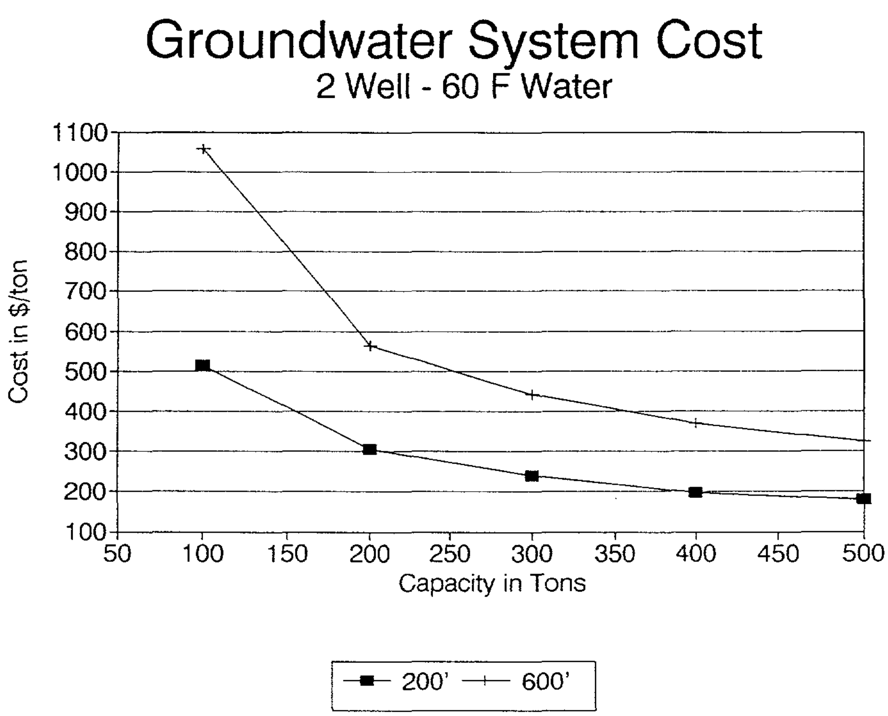
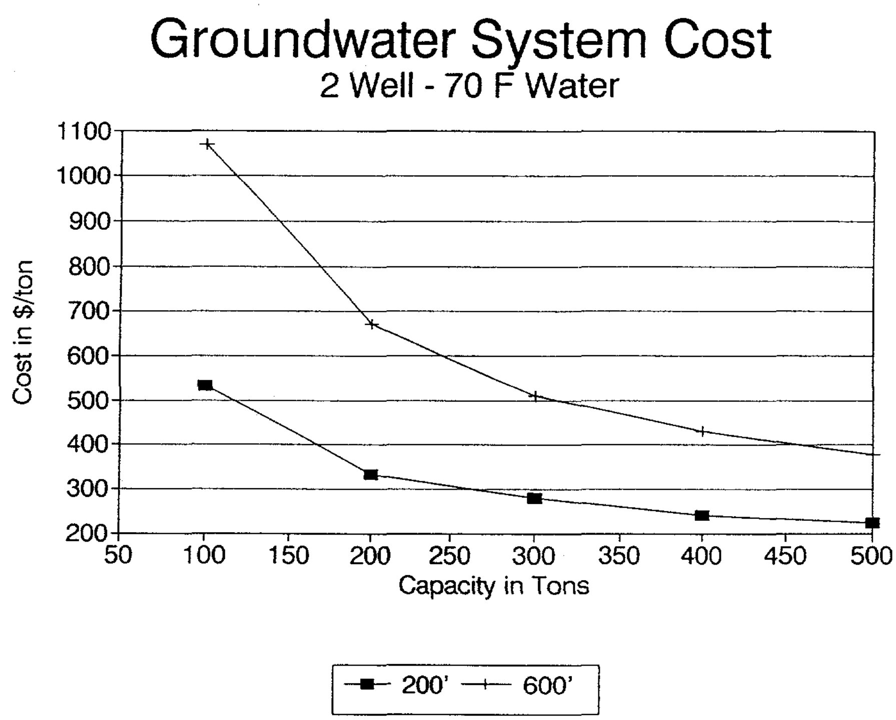


Figure 26


Groundwater System Cost
2 Well - 70 F Water
1100
1000
900
800
700
600
500
400
300
200
Cost in $/ton
50
100
150
200
250
300
350
400
450
500
Capacity in Tons
200'
600'

GROUND-COUPLED SYSTEM COSTS

The cost of the ground loop portion of a ground-coupled system is a function of the length of bore required per ton of system cooling capacity and the cost per foot of installing that bore. The recent popularity of these systems in certain areas has led to a highly competitive environment among contractors. In addition, the innovative techniques and equipment developed by some contractors have greatly reduced installation costs. Currently, larger commercial jobs are being installed for a little as $4 to $5 per foot of bore including all piping, drilling, manifolding and completion work (Kavanaugh, 1994; Braud, 1993; Braud, 1992; Lienau, 1994; Huttrer, 1994).

In areas where the technology is not as well developed or widely applied, these figures can be as high as $10 to $15 per foot.

For purposes of this report, a value of $5 per foot of bore has been used.

HYBRID SYSTEMS

Background

Hybrid systems are a variation of the ground-coupled system. The hybrid design was developed to address the high capital costs associated with the installation of a ground loop large enough to meet the peak cooling requirement in large commercial applications. Basically, the system is installed with a ground loop large enough to meet the peak space heating length requirement. In most commercial applications, the cooling length requirement exceeds the heating length requirement. The heat rejection necessary for the cooling load is accomplished with a combination of the smaller ground loop and a cooling tower. In most designs, the tower is of the closed circuit variety.

The economics of the hybrid system are most favorable in situations where there is a large difference between the heating and cooling length requirements; where loop installations costs are high and where system capacity is large (several hundred tons).

Hybrid System Costs

The cost of the hybrid system is partly related to ground coupled loop costs and partly to the tower. The relative portion of the total cost per ton attributable to the cooling tower and the loop is a function of the ratio of the ground loop length requirement for heating to the length requirement for cooling.

Consider a situation in which a 150-ton hybrid system is to be installed in an area in which the conditions would normally dictate a ground loop length of 200 ft per ton to meet the peak cooling requirement. The length required to meet the peak heating load is only 40% of the peak cooling requirement. This means that the smaller ground loop would only meet .40 x 200 tons or 80 tons of the peak 200 ton cooling load. The remaining 120 tons would be served by the cooling tower. This is the general approach taken to calculate the cost of hybrid type systems for this report.

The cost of the ground loop is based on a value of $5 per foot of ton including all piping, manifolds and completion.

Tower cost is based on vendor quotes for the tower itself (based on 75° WB, 85° - 95°F water range, closed circuit, centrifugal fan type). Also included in the tower figures are costs for electrical connections (magnetic starters and wiring) for fans and pumps, piping and concrete pad. Table 5 presents the basic cost data used for tower pricing.

Table 5
Hybrid System Tower Installed Costs

	50	100	200	300
Tower	$15,000	$26,700	$42,000	$60,000
Piping	3,700	5,940	7,650	7,650
Electrical	1,110	1,420	1,840	2,600
Pad	400	700	1,000	1,200
Sub-Total	$20,210	$34,760	$52,490	$71,450
Cost	3,030	5,210	7,870	10,700
Total	$23,420	$39,970	$60,360	$82,150
$/ton	$465	$400	$302	$274

Figure 27

Hybrid System Tower Cost
Installed w/ elec and piping

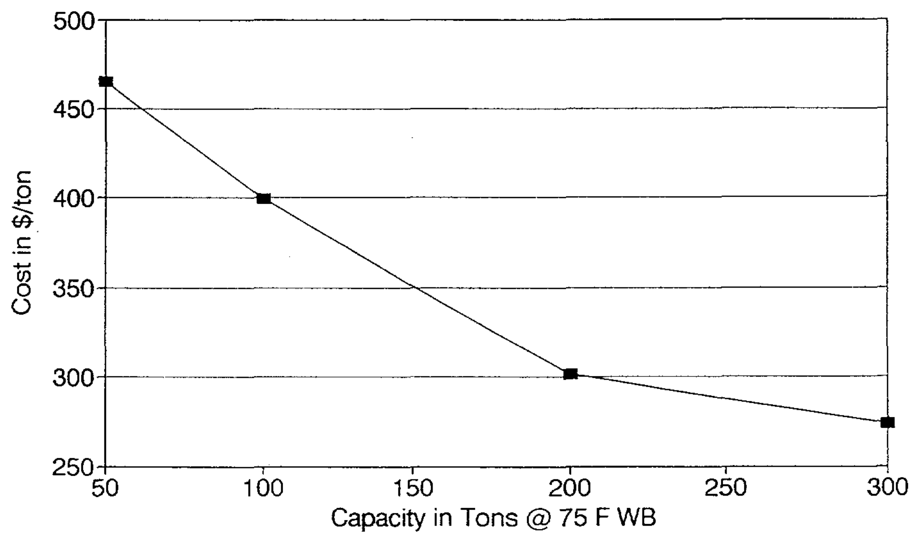


Figure 27 presents this data in graphical form. The curves shown are for 4 different length ratios .30 through .60. In each case, the unit cost (per ton) for a given capacity is determined by multiplying the basic ground coupled cost per ton by the length ratio. The result is added to the cost per ton for the tower multiplied by 1 - length ratio. For the example cited above, the cost per ton for the hybrid system would be:

= (.40 x $5/ft x 200 ft/ton) + (.60 x $380/ton)
=

Note value of $380/ton from Figure 27 is based on 120 tons (.60 x 200 tons).

Figures 28, 29 and 30 provide hybrid system cost data for 50°, 60° and 70° soil temperatures and length ratio values of .30 through .60.

Figure 28

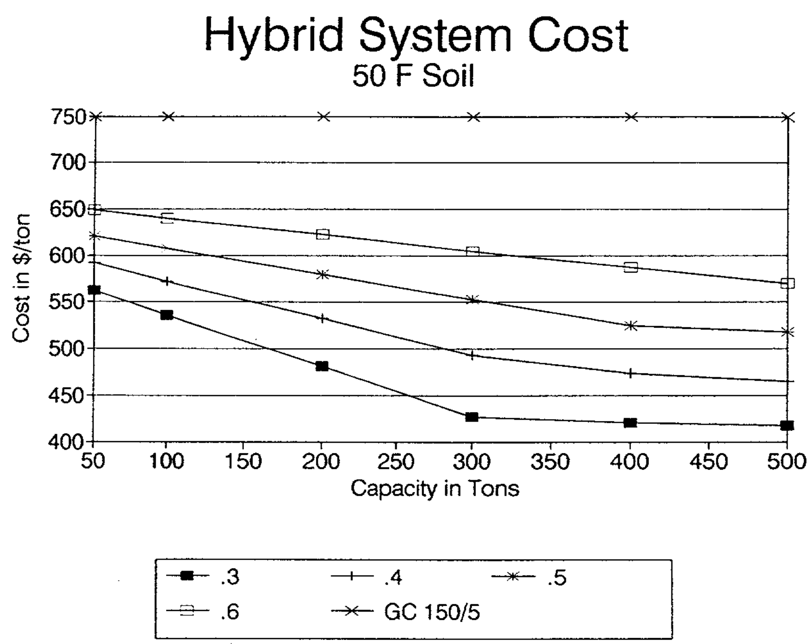


Figure 29

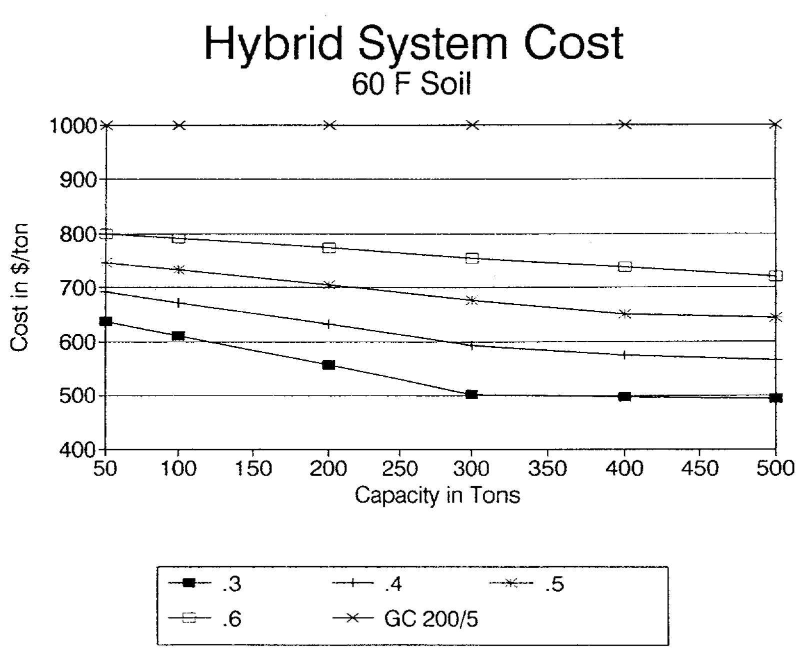
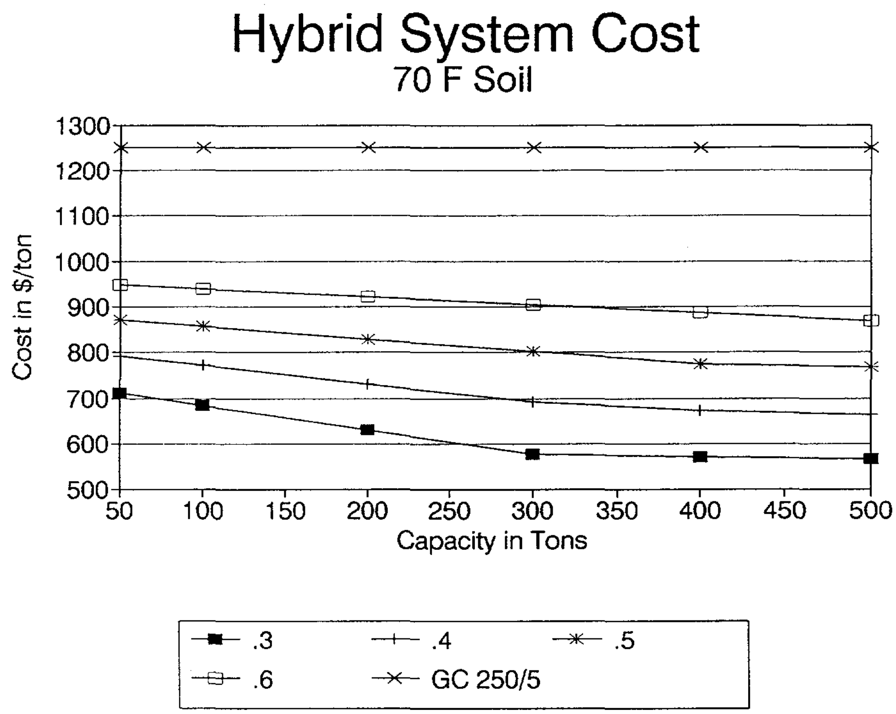


Figure 30



Hybrid System Cost
70 F Soil
1300
1200
1100
1000
900
800
700
600
500
Cost in $/ton
50
100
150
200
250
300
350
400
450
500
Capacity in Tons
.3
.4
.5
.6
GC 250/5

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APPENDIX B

Groundwater Calculations

Well costs

'92 survey Data - steel casing $/in.ft $/ft

8" well nat'l avg complete 3.09 24.75

6" " " " " 2.63 15.78

Gene's Data

soft drilling 1.80 $/in/ft <500'

casing @ .75 $.in/ft

1.80+.75 = 2.55 $/in.ft

domestic well % (NGWA Data)

drilling - 40.0

casing 56.1 %

other 3.9 %

add to gene's costs for "other"

10%

1.10 · 2.55 2.80

soft drilling >500' depth

3.00 $/in.ft + .75 in/ft

3.75 $/in ft + .10(3.75) 4.13

hard drilling <500'

$5.00 in/ft

NGWA Data

1970 Illinois Survey

8" 200' sand & gravel

$3900 @ 3%/yr

$(1.03)^{24} \cdot 3900 \div (8 \cdot 200)$ 4.95

1977 NGWA Survey

8" well mean cost 11.64/Ft

$(1.03)^{16} \cdot (11.64/8)$ 2.33

10" well mean cost $12.55/Ft

$(1.03)^{16} \cdot (12.55/10)$ 2.01

12" well mean cost $24.36/Ft

$(1.03)^{16} \cdot (24.36/12)$ 3.25

Wisconsin 1986

10" well consolidated Form 15$/ft

$((1.50\,(1.03)^{8}) + .75)\times 1.10$ 2.92

8" well $11/ft consolidated

$((11/8)\,(1.03)^{8} + .75)\times 1.10$ 2.74 3.06

Merrill school well - Brian

6" well 300' 100' casing

$3000 (Norm Seiny drilling)

add $900 for full casing 2.61

Campbell & Lehr 1966 data

deep sandstone 10" $.029 d^{1.87}$

400' - $.029(400)^{1.87} = 2129$

$2129\,(1.03)^{23} \div (10 \cdot 400)$? 1.21

sand and gravel cased wells

Sand stone / limestone

10" 600' - $4600

$4600 \cdot (1.03)^{24} \div (10" \cdot 600)$ 1.55

10" 200' $2200 2.24

10" 400' 6000 3.05

1968 Groundwater magazine

$10" = .983\, d^{1.45}$ – Sandstone

$300' = .983\,(300)^{1.45} = \$3840$

$(1.03)^{26} \cdot 3840 \div (10 \cdot 300)$ 2.60

Sand and gravel - same ref

$10" = 845\, d^{0.299}$

for 10" 150'

$= 845\,(150)^{0.299} = 3780$

$3780\,(1.03)^{26} \div (10 \cdot 150)$ 5.43

"deep" sandstone wells

10" 600' $.036\,(d)^{1.87}$

$.036\,(600)^{1.87} = 5642$

$5642\,(1.03)^{26} \div (10 \cdot 600)$ 2.03

1975 Nevada

14" well drilling only 21 $/ft

21/14 = 1.50 $/in.ft

$((1.03)^{13} \cdot 1.50 + .75)\, 1.10$ 3.72

1975 Texas

$18 /ft 12" case gravel pack

18 ÷ 12 = 1.50 $/in.ft

as above 3.72

Sand and gravel cased wells

12" · 850 $d^{0.373}$

$850(200)^{.373} = 6133$

$(1.03)^{20} \cdot 6133 \div (12 \cdot 200)$ 5.84

shallow sandstone/limestone

10" - 400' 0.339 $d^{1.45}$

$0.339(400)^{1.45} = 4974$

$4974 \cdot (1.03)^{20} \div (10 \cdot 400)$ 2.85

$\frac{67.7}{22}$ Avg all data (3.08)

APPENDIX C

Hybrid System Calculations

50	128.0	256.0	384.0	531.2
100	64.0	128.0	192.0	265.6
200	32.0	64.0	96.0	132.8
300	21.3	42.7	64.0	88.5
400	16.0	32.0	48.0	66.4
500	12.8	25.6	38.4	53.1

200 ft wells

	50	100	200	300	400	500
p.well	72	48	30	24	18	16.8
pump	119	106	79.2	69.7	52.3	44.6
test	24	12	6	4	3	2.4
drive	45.8	29.3	27.2	27.5	24.7	22.6
pipe	53.2	31.9	21.1	14	16.3	13
htx	88.4	62.4	54.4	51.9	51.2	50
controls	25.6	18	9	11.7	8.8	7
inj well	128	64	32	21.3	16	12.8
test	24	12	6	4	3	2.4
subtot	508	336	235	204	175	155
cont	76	50	35	31	26	23
total	584	386	270	235	202	178

400 ft Wells

p. well	144	96	54	40	30	33.6
inj well	256	128	64	42.7	32	25.6
subtot	780	496	321	266	221	201
cont	117	74	48	40	33	30
tot	897	570	369	305	254	231

600 ft Wells

p. well	216	144	84	64	48	43.2
pump	119	106	79.2	69.7	52.3	44.6
drive	58.6	45	41.2	37.6	28.2	29.8
inj. well	384	192	96	64	48	38.4
subtot	993	623	397	321	259	231
cont	149	93	60	48	39	35
total	1142	717	456	369	298	265

800 ft wells

p. well	298.8	199.2	111.6	64	48	54.2
inj. well	531.2	265.6	132.8	88.5	66.4	53.1
sub tot	1223	752	461	345	277	257
cont	183	113	69	52	42	38
total	1406	865	530	397	319	295
GC	1250	1250	1250	1250	1250	1250

dual well data

	100	200	300	400	500
p.well	72	48	36	30	28.8
pump	58.7	44.5	42.5	41.6	39.4
test	24	12	8	6	4.8
drive	22.9	14.6	18.2	13.6	16.5
pipe	53.2	31.9	24.7	21.1	16.8
htx	62.4	54.4	51.9	51.2	50
controls	18	9	11.7	8.8	7
inj well	128	64	42.6	32	25.6
test	24	12	8	6	4.8
subtot	463	290	244	210	194
cont	69	44	37	32	29
total	533	334	280	242	223

p.well	216	144	104	84	72
pump	119	106	80.1	79.2	73.5
test	24	12	8	6	4.8
drive	29.3	22.5	27.5	20.6	22.6
pipe	53.2	32	24.7	21.1	16.8
htx	62.4	54.4	51.9	51.2	50
controls	18	9	11.7	8.8	7
inj well	384	192	128	96	76.8
test	24	12	8	6	4.8
subtot	930	584	444	373	328
cont	139	88	67	56	49
total	1069	671	510	429	378

Hybrid Systems

Summary

	50	100	200	300
tower	15000	26700	42000	60000
pad	400	700	1000	1200
elec	1112	1421	1842	2604
piping	3705	5940	7650	7650
sub	20217	34761	52492	71454
cont	3033	5214	7874	10718
total	23250	39975	60366	82172
cost/ton	465	400	302	274

Electrical Magnetic starters and motor conncetion wire at $400

70 F Water @250 ft/ton and $5 per ft

	0.30	0.40	0.50	0.60	0.70	
50	712	792	871	949	1026	1250
100	685	772	858	940	1021	1250
200	631	733	830	923	1011	1250
300	577	693	803	905	1001	1250
400	571	674	775	888	991	1250
500	568	665	768	870	981	1250

50 F Water @150 ft/ton and $5 per ft

	0.3	0.4	0.5	0.6	0.7	
50	562	592	621	649	676	750
100	535	572	608	640	671	750
200	481	533	580	623	661	750
300	427	493	553	605	651	750
400	421	474	525	588	641	750
500	418	465	518	570	632	750

60 F Water @200 ft/ton and $5 per ft

	0.30	0.40	0.50	0.60	0.70	
50	637	692	746	799	851	1000
100	610	672	733	790	846	1000
200	556	633	705	773	836	1000
300	502	593	678	755	826	1000
400	496	574	650	738	816	1000
500	493	565	643	720	807	1000

70 F Water @250 ft/ton and $5 per ft

	0.30	0.40	0.50	0.60	0.70	
50	712	792	871	949	1026	1250
100	685	772	858	940	1021	1250
200	631	733	830	923	1011	1250
300	577	693	803	905	1001	1250
400	571	674	775	888	991	1250
500	568	665	768	870	981	1250

50 F Water @150 ft/ton and $5 per ft

	0.3	0.4	0.5	0.6	0.7	
50	562	592	621	649	676	750
100	535	572	608	640	671	750

Hybrid Systems

Summary

	50	100	200	300
tower	15000	26700	42000	60000
pad	400	700	1000	1200
elec	1112	1421	1842	2604
piping	3705	5940	7650	7650
sub	20217	34761	52492	71454
cont	3033	5214	7874	10718
total	23250	39975	60366	82172
cost/ton	465	400	302	274

Electrical Magnetic starters and motor conncetion wire at $400

	50	100	200	300
fan strtr	370	625	915	1250
pmp strtr	220	220	290	580
wire	400	400	400	400
fan conn	80	125	175	250
pmp conn	42	51	62	124
total	1112	1421	1842	2604

Piping - 40 ft pipe, 6 ells, 3 butterfly valves and flanges. welded sch 40

	4"	6"	8"
pipe	960	1640	2080
ells	840	1320	1800
valves	645	1020	1260
flanges	690	1080	1320
tees	570	880	1190
total	3705	5940	7650

50 F Water @150 ft/ton and $5 per ft

	0.3	0.4	0.5	0.6	0.7	
50	562	592	621	649	676	750
100	535	572	608	640	671	750
200	481	533	580	623	661	750
300	427	493	553	605	651	750
400	421	474	525	588	641	750
500	418	465	518	570	632	750

Hybrid Systems

Summary

	50	100	200	300

50 F WATER

Production Well Cost

Complete Wells at $3.00 per inch per foot
increase of 15% per 200 ft over 600 ft.
costs assume pump housing to 200 ft for 200 and 400 ft wells
3 to 400 ft for 600 and 800 ft wells

	Flow				
Depth	6	8	10	12	pump housing size
	<100	<200	<350	<700	flow
200	3600	4800	6000	7200	
400	7200	9600	10800	12000	
600	10800	14400	16800	19200	
800	14940	19920	22320	24720	

Water Flow Requirements

based on heat exchanger temperatures from below

Tons	50 F	60 F	70F
50	37.5	50	75
100	75	100	150
200	150	200	300
300	225	300	450
400	300	400	600
500	375	500	750

Production Well Cost

based on the above flow requirements and well costs

		50 F Water		
Tons	200	400	600	800
50	3600	7200	10800	14940
100	3600	7200	10800	14940
200	4800	9600	14400	19920
300	6000	10800	16800	22320
400	6000	10800	16800	22320
500	7200	12000	19200	24720
50	72	144	216	298.8
100	36.0	72.0	108.0	149.4
200	24.0	48.0	72.0	99.6
300	20.0	36.0	56.0	74.4

400	15.0	27.0	42.0	55.8
500	14.4	24.0	38.4	49.4

Pump Test Cost
Interstate Pump $25/hr for duration of test
Assume 2 8 hr tests over 2 days
$25*24*2+1200

50	1200	24
100	1200	12
200	1200	6
300	1200	4
400	1200	3
500	1200	2.4

Submersible Pumps

hp	$/hp	pump	column	wire	elec	inst	200/400 total
5	230	1150	744	90	290	660	2934
10	210	2100	1194	90	370	700	4454
15	190	2850	1194	90	453	715	5302
20	160	3200	2833	90	542	775	7440
25	144	3600	2833	404	625	850	8312
30	139	4175	3687	404	683	1030	9979
40	135	5400	3687	404	818	1100	11409
50	130	6500	3687	404	915	1250	12756
75	130	9750	3687	404	1357	1250	16448

tons	flow	200/ 400	cost above	cost/ ton	600/ 800	cost above	cost/ ton
50	37.5	2.7	2934	58.7	4.6	3966	79.3
100	75	5.3	4454	44.5	9.3	5948	59.5
200	150	10.7	5302	26.5	18.6	10596	53.0
300	225	16.0	7440	24.8	27.9	14376	47.9
400	300	21.4	8312	20.8	37.1	15830	39.6
500	375	26.7	9979	20.0	46.4	17222	34.4

Frequency Drive Cost

			'86 Data	86/'94	Means starter labor
1	1170	1170.0			
2	1300	650.0			
3	1450	483.3			
5	1770	354.0	782	0.45	105
7.5	2160	288.0	618	0.47	128
10	2780	278.0	527	0.53	150
15	3380	225.3	436	0.52	173
20	4300	215.0	373	0.58	196

400	15.0	27.0	42.0	55.8
500	14.4	24.0	38.4	49.4

Pump Test Cost
Interstate Pump $25/hr for duration of test
Assume 2 8 hr tests over 2 days
$25*24*2+1200

50	1200	24
100	1200	12
200	1200	6
300	1200	4
400	1200	3
500	1200	2.4

Submersible Pumps

hp	$/hp	pump	column	wire	elec	inst	200/400 total
5	230	1150	744	90	290	660	2934
10	210	2100	1194	90	370	700	4454
15	190	2850	1194	90	453	715	5302
20	160	3200	2833	90	542	775	7440
25	144	3600	2833	404	625	850	8312
30	139	4175	3687	404	683	1030	9979
40	135	5400	3687	404	818	1100	11409
50	130	6500	3687	404	915	1250	12756
75	130	9750	3687	404	1357	1250	16448

tons	flow	200/ 400	cost above	cost/ ton	600/ 800	cost above	cost/ ton
50	37.5	2.7	2934	58.7	4.6	3966	79.3
100	75	5.3	4454	44.5	9.3	5948	59.5
200	150	10.7	5302	26.5	18.6	10596	53.0
300	225	16.0	7440	24.8	27.9	14376	47.9
400	300	21.4	8312	20.8	37.1	15830	39.6
500	375	26.7	9979	20.0	46.4	17222	34.4

Frequency Drive Cost

			'86 Data	86/'94	Means starter labor
1	1170	1170.0			
2	1300	650.0			
3	1450	483.3			
5	1770	354.0	782	0.45	105
7.5	2160	288.0	618	0.47	128
10	2780	278.0	527	0.53	150
15	3380	225.3	436	0.52	173
20	4300	215.0	373	0.58	196

25	5230	209.2	344	0.61	218
30	6480	216.0	306	0.71	227
40	8000	200	282	0.71	245
50	9600	192	270	0.71	265
75	10950	146	206	0.71	334
100	14500	145	205	0.71	403

tons	200/ 400	cost above	cost/ ton	600/ 800	cost above	cost/ ton
50	2.7	1875	37.5	4.6	1875	37.5
100	5.3	2930	29.3	9.3	2930	29.3
200	10.7	3553	17.8	18.6	4496	22.5
300	16.0	4496	15.0	27.9	6707	22.4
400	21.4	5448	13.6	37.1	8245	20.6
500	26.7	6707	13.4	46.4	9865	19.7

Burried Piping Costs

from Means for Class 160 PVC

Size	pipe & inst	trench bkfill bedding
3	5.48	3.99
4	6.65	3.99
6	10.05	3.99
8	17.75	3.99

50 and 60 Water

tons	pipe size	feet of pipe	cost/ foot	Total cost	Cost/ Ton
50	3	300	8.87	2661	53.2
100	4	300	10.64	3192	31.9
200	6	300	14.04	4212	21.1
300	6	300	14.04	4212	14.0
400	6	300	14.04	4212	10.5
500	8	300	21.74	6522	13.0

Heat exchanger cost
from curves in Direct Use Handbook
based on 1000 Btu/hr sqft F (tons*15000)/(1000*LMTD)

50 F Water, 50 to 85/85 to 95

tons	sqft	cost/ sqft	Install $	instld 15% O&P	cost/ ton
50	45.8	48	910	3575	71.5
100	91.6	33.6	1075	4775	47.8
200	183.2	24	1275	6523	32.6
300	274.8	24	1550	9366	31.2
400	366.4	24	1675	12038	30.1
500	458	24	1975	14912	29.8

controls - 2-way valve and temperature sensor w/ dual set point controller as part of ddc system.
$600 (input)plus$350(output)plus valve

	flow	valve	total	$/ton
50	37.5	330	1280	25.6
100	75	845	1795	18.0
200	150	845	1795	9.0
300	225	845	1795	6.0
400	300	2550	3500	8.8
500	375	2550	3500	7.0

Injection Well Cost
based on 8" with unit costs as above

Depth	$4.00
200	6400
400	12800
600	19200
800	26560

	200	400	600	800
50	128.0	256.0	384.0	531.2
100	64.0	128.0	192.0	265.6
200	32.0	64.0	96.0	132.8
300	21.3	42.7	64.0	88.5
400	16.0	32.0	48.0	66.4
500	12.8	25.6	38.4	53.1

200 ft wells

	50	100	200	300	400	500
p.well	72	36	24	20	15	14.4
pump	58.7	44.5	26.5	24.8	20.8	20
test	24	12	6	4	3	2.4
drive	37.5	29.3	17.8	15	13.6	13.4
pipe	53.2	31.9	21.1	14	10.5	13
htx	71.5	47.8	32.6	31.2	30.1	29.8

controls	25.6	18	9	6	8.8	7
inj well	128	64	32	21.3	16	12.8
test	24	12	6	4	3	2.4
subtot	423	260	151	120	106	101
cont	63	39	23	18	16	15
total	486	298	174	138	122	116

400 ft Wells

p. well	144	72	48	36	27	24
inj well	256	128	64	42.7	32	25.6
subtot	695	396	231	178	149	138
cont	104	59	35	27	22	21
tot	799	455	266	204	171	158

600 ft Wells

p. well	216	108	72	56	42	38.4
pump	79.3	59.5	53	47.9	39.6	34.4
drive	37.5	29.3	22.5	22.4	20.6	19.7
inj. well	384	192	96	64	48	38.4
subtot	915	511	318	250	206	186
cont	137	77	48	37	31	28
total	1052	587	366	287	236	213

800 ft wells

p. well	298.8	149.4	99.6	74.4	55.8	49.4
inj. well	531.2	265.6	132.8	88.5	66.4	53.1
sub tot	1145	626	383	292	238	211
cont	172	94	57	44	36	32
total	1317	719	440	336	273	243
GC	750	750	750	750	750	750

Dual Well Data

	100	200	300	400	500
p.well	72	36	28	24	21.6
pump	59	44.5	32.5	26.5	25.5
test	24	12	8	6	4.8
drive	18.8	14.7	11.8	8.9	8.9
pipe	53.2	32	24.7	21	16.8
htx	47.8	32.6	31.2	30.1	29.8

controls	18	9	6	8.8	7
inj well	128	64	42.6	32	25.6
test	24	12	8	6	4.8
subtot	445	257	193	163	145
cont	67	39	29	24	22
total	512	295	222	188	167

p.well	216	108	84	72	84.5
pump	79	59.5	55.1	53	49.9
test	24	12	8	6	4.8
drive	18.8	14.6	15	11.2	13.4
pipe	53.2	32	24.7	21	16.8
htx	47.8	32.6	31.2	30.1	29.8
controls	18	9	6	8.8	7
inj well	384	192	128	96	64
test	24	12	8	6	4.8
subtot	865	472	360	304	275
cont	130	71	54	46	41
total	995	542	414	350	316

60 F WATER

Production Well Cost

Complete Wells at $3.00 per inch per foot
increase of 15% per 200 ft over 600 ft.
costs assume pump housing to 200 ft for 200 and 400 ft wells
3 to 400 ft for 600 and 800 ft wells

		Flow			
Depth	6	8	10	12	pump housing size
	<100	<200	<350	<700	flow
200	3600	4800	6000	7200	
400	7200	9600	10800	12000	
600	10800	14400	16800	19200	
800	14940	19920	22320	24720	

Water Flow Requirements
based on heat exchanger temperatures from below

Tons	50 F	60 F	70F
50	37.5	50	75
100	75	100	150
200	150	200	300
300	225	300	450
400	300	400	600
500	375	500	750

Production Well Cost

based on the above flow requirements and well costs

60 F Water

50	3600	7200	10800	14920
100	3600	7200	10800	14920
200	4800	9600	14400	19920
300	6000	10800	16800	22320
400	7200	12000	19200	24720
500	7200	12000	19200	24720
50	72.0	144.0	216.0	298.4
100	36.0	72.0	108.0	149.2
200	24.0	48.0	72.0	99.6
300	20.0	36.0	56.0	74.4
400	18.0	30.0	48.0	61.8
500	14.4	24.0	38.4	49.4

Pump Test Cost
Interstate Pump $25/hr for duration of test
Assume 2 8 hr tests over 2 days
$25*24*2+1200

50	1200	24	
100	1200	12	24
200	1200	6	12
300	1200	4	8
400	1200	3	6
500	1200	2.4	4.8

Submersible Pumps

hp	$/hp	pump	column	wire	elec	inst	200/400 total
5	230	1150	744	90	290	660	2934
10	210	2100	1194	90	370	700	4454
15	190	2850	1194	90	453	715	5302
20	160	3200	2833	90	542	775	7440
25	144	3600	2833	404	625	850	8312
30	139	4175	3687	404	683	1030	9979
40	135	5400	3687	404	818	1100	11409
50	130	6500	3687	404	915	1250	12756
75	130	9750	3687	404	1357	1250	16448

tons	flow	200/ 400	cost above	cost/ ton	600/ 800	cost above	cost/ ton
50	50	3.6	2934	58.7	6.2	5948	119.0
100	100	7.1	4454	44.5	12.4	6801	68.0
200	200	14.3	5302	26.5	24.8	11804	59.0
300	300	21.4	8312	27.7	37.1	15830	52.8
400	400	28.5	9979	24.9	49.5	17222	43.1
500	500	35.6	11409	22.8	61.9	20914	41.8

Frequency Drive Cost

					Means	
1	1170	1170.0			Means	
2	1300	650.0	'86 Data	86/'94	starter	
3	1450	483.3			labor	
5	1770	354.0	782	0.45	105	1875
7.5	2160	288.0	618	0.47	128	2288
10	2780	278.0	527	0.53	150	2930
15	3380	225.3	436	0.52	173	3553
20	4300	215.0	373	0.58	196	4496
25	5230	209.2	344	0.61	218	5448
30	6480	216.0	306	0.71	227	6707
40	8000	200	282	0.71	245	8245
50	9600	192	270	0.71	265	9865
75	10950	146	206	0.71	334	11284
100	14500	145	205	0.71	403	14903

tons	200/ 400	cost above	cost/ ton	600/ 800	cost above	cost/ ton	200/4/2
50	3.6	1875	37.5	6.2	2930	58.6	
100	7.1	2930	29.3	12.4	3553	35.5	18.75
200	14.3	3553	17.8	24.8	5448	27.2	14.7
300	21.4	5448	18.2	37.1	8245	27.5	11.8
400	28.5	6707	16.8	49.5	9865	24.7	8.88
500	35.6	8245	16.5	61.9	11284	22.6	10.9

Burried Piping Costs

from Means for Class 160 PVC

Size	pipe & inst	trench bkfill bedding	
3	5.48	3.99	9.47
4	6.65	3.99	10.64
6	10.05	3.99	14.04
8	17.75	3.99	21.74

50 and 60 Water

tons	pipe size	feet of pipe	cost/ foot	Total cost	Cost/ Ton	2 well
50	3	300	9.47	2841	56.8	
100	4	300	10.64	3192	31.9	56.8
200	6	300	14.04	4212	21.1	31.9
300	6	300	14.04	4212	14.0	24.7
400	6	300	14.04	4212	10.5	21
500	8	300	21.74	6522	13.0	16.8

Heat exchanger cost

from curves in Direct Use Handbook
based on 1000 Btu/hr sqft F (tons*15000)/(1000*LMTD)

60 F water ,85 to 95/60 to 90

tons	sqft	cost/ sqft	Install $	instld 15% O&P	cost/ ton
50	60.4	48	910	4380	87.6
100	120.8	27.6	1075	5070	50.7
200	241.4	24	1275	8129	40.6
300	362.4	24	1550	11785	39.3
400	483.2	24	1675	15263	38.2
500	604	24	1975	18941	37.9

controls - 2-way valve and temperature sensor w/ dual set point controller as part of ddc system.
$600 (input)plus$350(output)plus valve

	flow	valve	total	$/ton
50	50	330	1280	25.6
100	100	845	1795	18.0
200	200	845	1795	9.0
300	300	2550	3500	11.7
400	400	2550	3500	8.8
500	500	2550	3500	7.0

Injection Well Cost
based on 8" with unit costs as above

Depth	$4.00
200	6400
400	12800
600	19200
800	26560

	1 well				2 well		
200	400	600	800	200	400	600	800
128.0	256.0	384.0	531.2	256	512	768	1062
64.0	128.0	192.0	265.6	128	256	384	531
32.0	64.0	96.0	132.8	64	128	192	265.6
21.3	42.7	64.0	88.5	42.6	85.3	128	177
16.0	32.0	48.0	66.4	32	64	96	132.8
12.8	25.6	38.4	53.1	25.6	51.2	76.8	106

200 ft wells

50	100	200	300	400	500
72	36	24	20	18	14.4
58.7	44.5	26.5	27.7	24.9	22.8
24	12	6	4	3	2.4

37.5	29.3	17.8	18.2	16.8	16.5
56.8	31.9	21.1	14	10.5	13
87.6	50.7	40.6	39.3	38.2	37.9
25.6	18	9	11.7	8.8	7
128	64	32	21.3	16	12.8
24	12	6	4	3	2.4

442	262	159	140	121	115
66	39	24	21	18	17
509	302	183	161	139	132

400 ft Wells

144	72	48	36	30	24
256	128	64	42.6	32	25.6
714	398	239	198	167	152
107	60	36	30	25	23
821	458	275	227	192	174

600 ft Wells

216	108	72	56	48	38.4
119	68	59	52.8	43.1	41.8
58.6	35.5	27.2	27.5	24.7	22.6
384	192	96	64	48	38.4
996	528	337	273	227	204
149	79	51	41	34	31
1145	607	387	314	261	234

800 ft wells

298.4	149.2	99.6	74.4	61.8	49.4
531.2	265.6	132.8	88.5	66.4	53.1
1225	643	401	316	260	230
184	96	60	47	39	34
1409	739	461	364	298	264
1000	1000	1000	1000	1000	1000

dual well data

100	200	300	400	500
72	36	28	24	21.6
58.7	44.5	35.5	26.5	27.2
24	12	8	6	4.8
18.8	14.7	11.8	8.9	10.9
53.2	31.9	24.7	21.1	16.8
50.7	40.6	39.3	38.2	37.9
18	9	11.7	8.8	7
128	64	42.6	32	25.6
24	12	8	6	4.8
447	265	210	172	157
67	40	31	26	23

515	304	241	197	180
216	108	84	72	62.4
119	68	62	59	55.3
24	12	8	6	4.8
29.3	17.8	18.2	13.6	16.5
53.2	32	24.7	21.1	16.8
50.7	40.6	39.3	38.2	37.9
18	9	11.7	8.8	7
384	192	128	96	76.8
24	12	8	6	4.8

918	491	384	321	282
138	74	58	48	42
1056	565	441	369	325

70 F WATER

Production Well Cost

Complete Wells at $3.00 per inch per foot
increase of 15% per 200 ft over 600 ft.
costs assume pump housing to 200 ft for 200 and 400 ft wells
3 to 400 ft for 600 and 800 ft wells

	Flow				
Depth	6	8	10	12	pump housing size
	<100	<200	<350	<700	flow
200	3600	4800	6000	7200	
400	7200	9600	10800	12000	
600	10800	14400	16800	19200	
800	14940	19920	22320	24720	

Water Flow Requirements
based on heat exchanger temperatures from below

Tons	50 F	60 F	70F
50	37.5	50	75
100	75	100	150
200	150	200	300
300	225	300	450
400	300	400	600
500	375	500	750

Production Well Cost

based on the above flow requirements and well costs

70 F Water

50	3600	7200	10800	14940
100	4800	9600	14400	19920
200	6000	10800	16800	22320
300	7200	12000	19200	19200
400	7200	12000	19200	19200
500	8400	16800	21600	27120

50	72.0	144.0	216.0	298.8
100	48.0	96.0	144.0	199.2
200	30.0	54.0	84.0	111.6
300	24.0	40.0	64.0	64.0
400	18.0	30.0	48.0	48.0
500	16.8	33.6	43.2	54.2

Pump Test Cost
Interstate Pump $25/hr for duration of test
Assume 2 8 hr tests over 2 days
$25*24*2+1200

50	1200	24
100	1200	12
200	1200	6
300	1200	4
400	1200	3
500	1200	2.4

Submersible Pumps

hp	$/hp	pump	column	wire	elec	inst	200/400 total
5	230	1150	744	90	290	660	2934
10	210	2100	1194	90	370	700	4454
15	190	2850	1194	90	453	715	5302
20	160	3200	2833	90	542	775	7440
25	144	3600	2833	404	625	850	8312
30	139	4175	3687	404	683	1030	9979
40	135	5400	3687	404	818	1100	11409
50	130	6500	3687	404	915	1250	12756
75	130	9750	3687	404	1357	1250	16448

tons	flow	200/ 400	cost above	cost/ ton	600/ 800	cost above	cost/ ton
50	75	5.3	2934	58.7	9.3	5948	119.0
100	150	10.7	4454	44.5	18.6	10596	106.0

200	300	21.4	8312	41.6	37.1	15830	79.2
300	450	32.1	11409	38.0	55.7	20914	69.7
400	600	42.8	12756	31.9	74.3	20914	52.3
500	750	53.4	16448	32.9	92.9	22278	44.6

Frequency Drive Cost

			'86 Data	86/'94	Means starter labor	
1	1170	1170.0				
2	1300	650.0				
3	1450	483.3				
5	1770	354.0	782	0.45	105	1875
7.5	2160	288.0	618	0.47	128	2288
10	2780	278.0	527	0.53	150	2930
15	3380	225.3	436	0.52	173	3553
20	4300	215.0	373	0.58	196	4496
25	5230	209.2	344	0.61	218	5448
30	6480	216.0	306	0.71	227	6707
40	8000	200	282	0.71	245	8245
50	9600	192	270	0.71	265	9865
75	10950	146	206	0.71	334	11284
100	14500	145	205	0.71	403	14903

tons	200/ 400	cost above	cost/ ton	600/ 800	cost above	cost/ ton
50	5.3	2288	45.8	9.3	2930	58.6
100	10.7	2930	29.3	18.6	4496	45.0
200	21.4	5448	27.2	37.1	8245	41.2
300	32.1	8245	27.5	55.7	11284	37.6
400	42.8	9865	24.7	74.3	11284	28.2
500	53.4	11284	22.6	92.9	14903	29.8

Burried Piping Costs

from Means for Class 160 PVC

Size	pipe & inst	trench bkfill bedding
3	5.48	3.99
4	6.65	3.99
6	10.05	3.99
8	17.75	3.99

70 Water

0
0

tons	pipe size	feet of pipe	cost/ foot	Total cost	Cost/ Ton

50	3	300	8.87	2661	53.2
100	4	300	10.64	3192	31.9
200	6	300	14.04	4212	21.1
300	6	300	14.04	4212	14.0
400	8	300	21.74	6522	16.3
500	8	300	21.74	6522	13.0

Heat exchanger cost
from curves in Direct Use Handbook
based on 1000 Btu/hr sqft F (tons*15000)/(1000*LMTD)

70 Water, 85 to 95/70 to 90

50	82.4	33.6	1075	4420	88.4
100	164.8	25.2	1275	6242	62.4
200	329.6	24	1550	10879	54.4
300	494.4	24	1675	15571	51.9
400	659.2	24	1975	20465	51.2
500	824	24	1975	25013	50.0

controls - 2-way valve and temperature sensor w/ dual set point controller as part of ddc system.
$600 (input)plus$350(output)plus valve

	flow	valve	total	$/ton
50	75	330	1280	25.6
100	150	845	1795	18.0
200	300	845	1795	9.0
300	450	2550	3500	11.7
400	600	2550	3500	8.8
500	750	2550	3500	7.0

Injection Well Cost
based on 8" with unit costs as above

Depth	$4.00	$7.00	
200	6400	11200	
400	12800	22400	
600	19200	33600	
800	26560	46480	
200	400	600	800