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A Preliminary Economic Analysis of Aquifer Winter-Chill Storage at the John F. Kennedy Airport

E. C. Fox J. F. Thomas

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A PRELIMINARY ECONOMIC ANALYSIS OF AQUIFER WINTER-CHILL STORAGE AT THE JOHN F. KENNEDY AIRPORT

E. C. Fox J. F. Thomas

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A PRELIMINARY ECONOMIC ANALYSIS OF AQUIFER WINTER-CHILL STORAGE AT THE JOHN F. KENNEDY AIRPORT

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ABSTRACT

A conceptual design was formulated in conjunction with a cost analysis to determine the feasibility of retrofitting the present John F. Kennedy (JFK) airport air-conditioning system with an aquifer cold water storage system. It appears technically feasible to chill and store aquifer water at the airport site during the winter months for later air-conditioning use. However, the economic analysis shows that although a significant energy savings is realized, the money saved from reduced energy costs would not be enough to recover the necessary capital investment over a 20-year period. JFK airport may be a poor economic choice for an aquifer cold water storage demonstration site due to site specific problems, and other sites may provide economic incentive.

1. INTRODUCTION

The Department of Energy (DOE) has recognized cold water storage in conjunction with a cold capture system to be a potentially attractive alternative to conventional air-conditioning methods. Desert Reclamation Industries, Inc., has conducted a DOE-sponsored study to determine the feasibility of using such a system for air conditioning at the John F. Kennedy (JFK) airport. This site was selected for a case study due to the presence of an apparently suitable aquifer in the underlying strata, because of the large air-conditioning load, and because it is a highly visible site for a future demonstration project. This report is an independent follow up study to evaluate the cold water capture/aquifer storage concept as it applies to the specific JFK site.

In general, when the proper geological conditions are present, a confined aquifer can efficiently store large quantities of cooled water until needed for air conditioning. Wells can be used to bring the water to the surface in the winter months to be cooled by the winter cold via some heat exchange method. Cold water is then reinjected into the aquifer for summer use.

Presently JFK airport uses a water chilling system composed of electric compressive units (for base load) and adsorption chillers. The adsorption chillers are powered by hot water from oil/gas boilers. The proposed winter cold capture/aquifer storage system would replace the existing water chilling system, and must meet the design criteria for the existing air-conditioning equipment used in the terminal buildings.

2. SUMMARY

The intent of this report is to present the analysis of a winter chill cold water storage project sited at the John F. Kennedy (JFK) Airport. The cold source is the winter environment and the storage system is water in a confined aquifer. The purpose is to displace the use of oil and electricity which is presently being used for air conditioning the airport terminal buildings.

The results indicate that there are insufficient economic incentives to justify a demonstration of this concept's economic viability at the JFK site. Specifically, there is not enough potential savings of fuel to pay for the required capital expenditure over the 20-year life of the project. However, it is misleading to draw general conclusions from these site specific results. One consideration is the retrofit nature of the project. The location of taxiways, runways, and presently installed utilities drives the costs of the installation upward. Further, the labor costs and specifically the cost of well drilling in the Long Island area is much higher than other regions of the country. When all these factors are considered, other sites could provide stronger incentives.

It was also concluded that significant cost reductions could be realized if the need for heat exchangers were eliminated. However it is doubtful that this could be achieved for the JFK site, as several technical difficulties would need to be resolved.

3. CHILLED WATER-STORAGE OPTIONS

Two options for capture and storage of winter chill were chosen for analysis of the aquifer concept relative to the JFK site. These options differ in the method in which the well water is cooled. One method would use cooling towers to chill the water with cold winter air. The other option could take advantage of the near freezing water that is adjacent to the JFK site. The cold Jamaica Bay water would be used to cool the well water in a series of heat exchangers.

3.1 Cooling Tower Option

A simplified schematic of the aquifer cold water storage system is shown in Fig. 3.1. The existing chilled water air conditioning system at JFK airport requires 7.2°C (45°F) water. This limit is placed on the system to maintain the airport terminals within a comfortable relative humidity range. It has been assumed that the storage and piping system has a thermal efficiency of 85%, therefore 6.1°C (43°F) water is to be injected into the storage volume to achieve design conditions.

As seen in Fig. 3.1, the cooling tower water is cooled from 10°C (50°F) to 3.3°C (38°F) and transported to a heat exchanger where the aquifer water temperature is reduced to 6.1°C (43°F). Aquifer water is not cooled directly with cooling towers because the subsequent aeration would cause oxidation of some of the dissolved solids (e.g. iron compounds) and could result in precipitation of these solids and plugging of the well. Additionally, oxidation would promote organic growth, again with the potential of plugging the well.

3.2 Jamaica Bay Option

The Jamaica Bay is an inlet of the Atlantic ocean, which forms a border of the JFK airport (Fig. 3.2). The average monthly water temperatures of the bay vary between 1.7—3.3°C (35—38°F) from December through February. It is proposed that this cold source could be used to cool water to be stored in the aquifer below the airport. A schematic of the

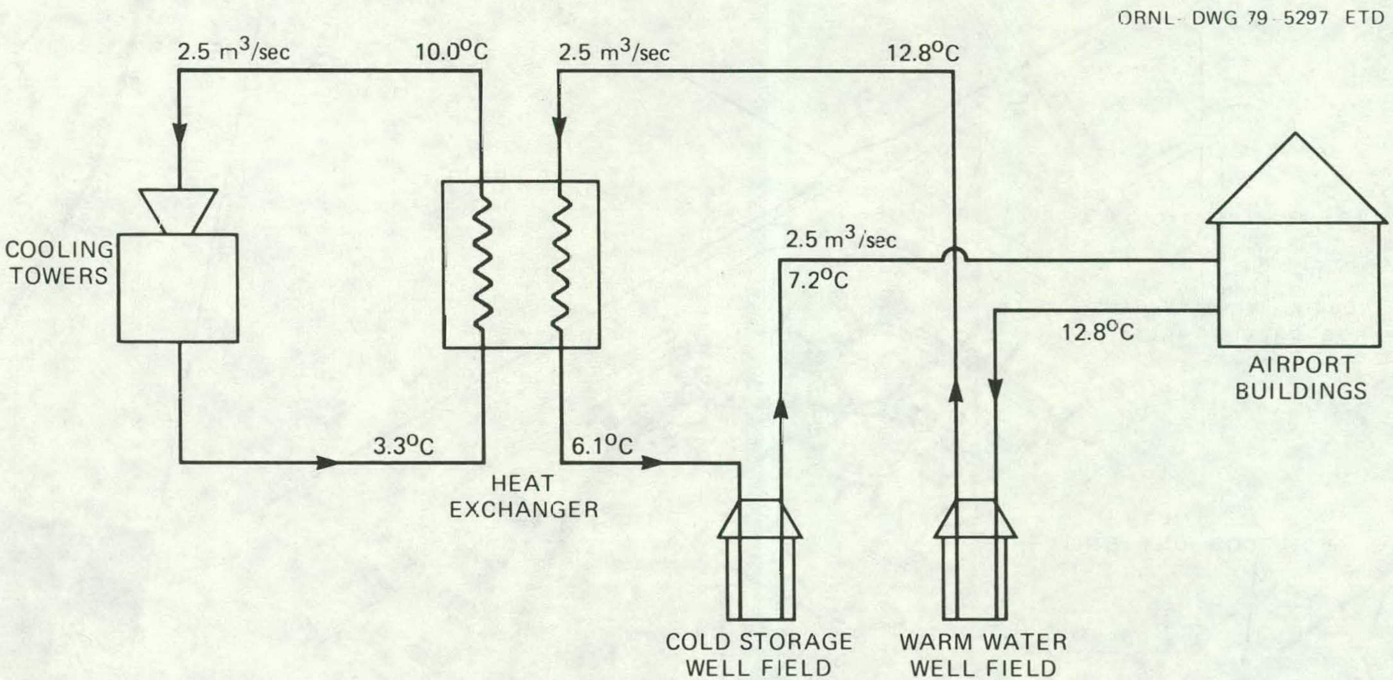

Fig. 3.1. Cooling tower system.

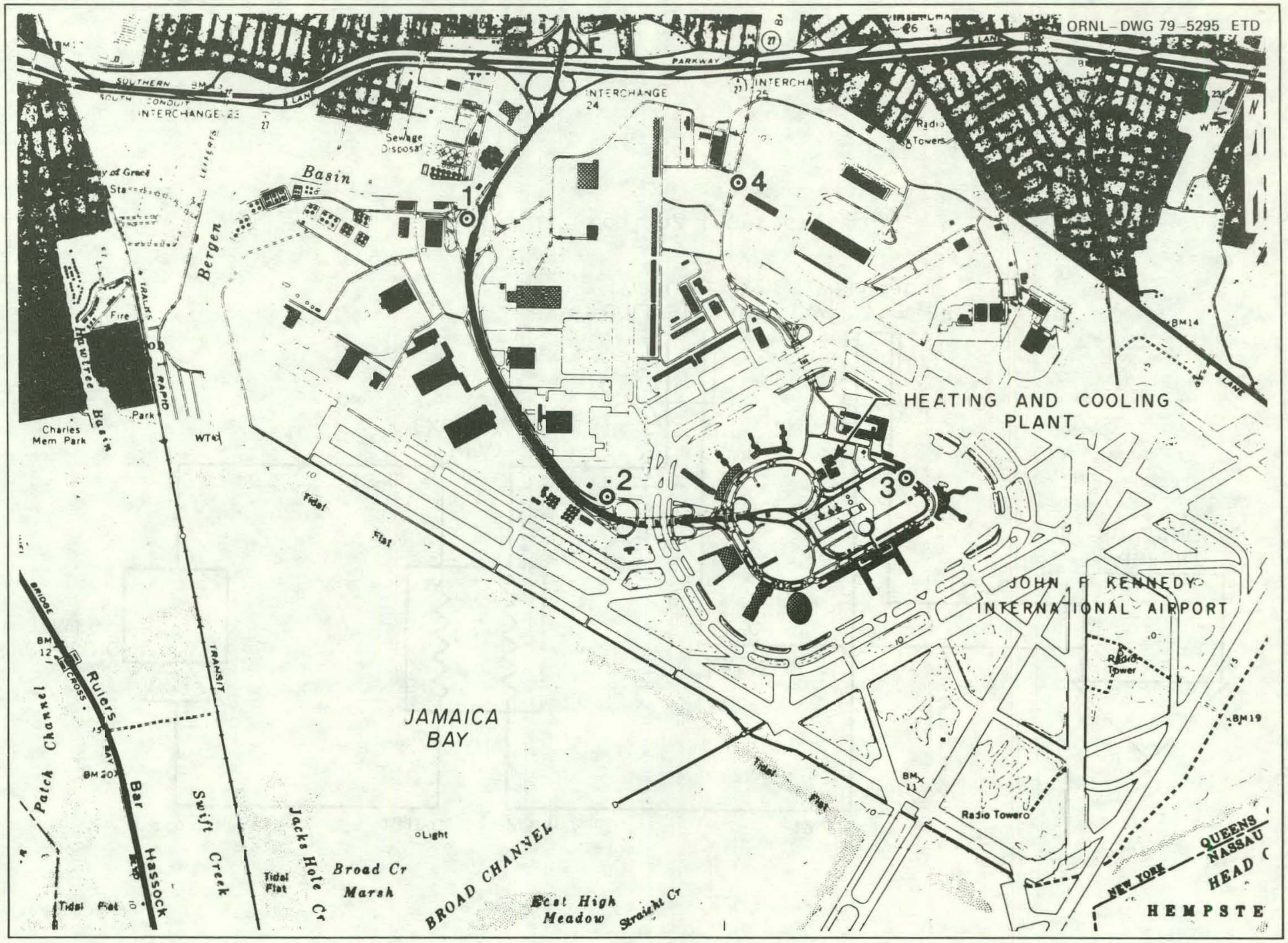

Fig. 3.2. John F. Kennedy airport.

Jamaica Bay option is presented in Fig. 3.3. Water would be pumped out of the aquifer and piped approximately 1520 m to the bay pumping station. The well water would be heat exchanged with the bay water in a series of shell and tube heat exchangers. Because the bay water is brackish and possibly polluted, it is not feasible to use the water directly; thus, heat exchangers must be used. After the well water is cooled, it is then returned to the airport and reinjected into the aquifer.

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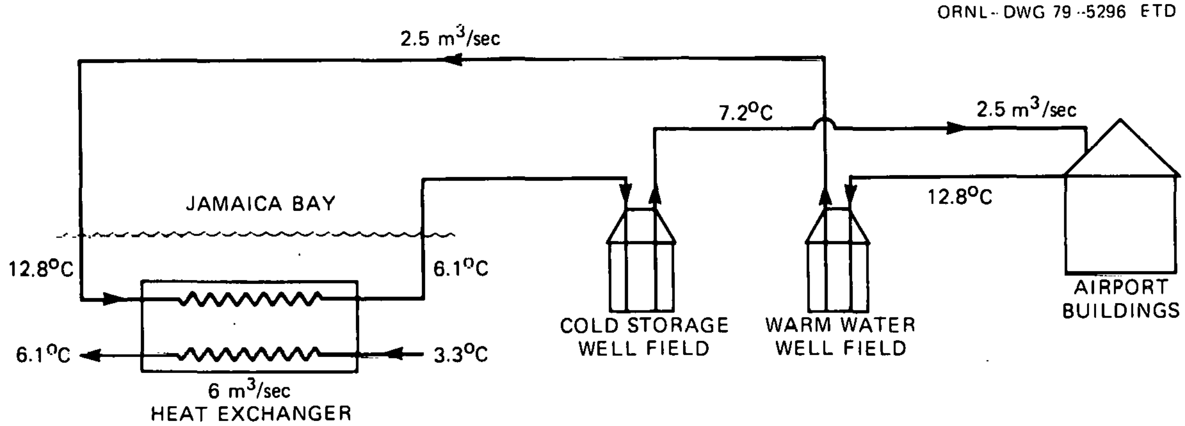

Fig. 3.3. Jamaica Bay system.

4. AQUIFER DESCRIPTION

From studies by Dames and Moore,[1,2] it is known that several aquifer layers lie below the JFK airport. The only aquifer considered acceptable for the chilled water storage project is known as the Jameco-Magothy layer. This aquifer is composed chiefly of two layers, the Jameco layer, which consists of sand and gravel, and below this the Magothy sands. Immediately above and below the aquifer layers are clays which are relatively impervious to water flow. The upper Gardiners Clay layer is important as it should provide a barrier to subsidence, although further information is necessary to verify that there are no holes or gaps in this layer.

Four test wells were drilled at JFK airport by Dames and Moore[2] at the numbered sites shown in Fig. 3.2. Some of pertinent well test results are presented in Table 4.1. Estimates from the available information reveal the Jameco layer to begin at about 61 m (200 ft) from the surface and to average 27 m (90 ft) in thickness, with the Magothy sand layer averaging 18 m (60 ft) thick. These estimates apply only to the regions near test wells 2, 3, and 4; the aquifer was found to be relatively thin near well 1. It should be noted that the aquifer layer thicknesses in regions between the test wells are not known and were assumed to vary linearly for estimating purposes.

A thorough analysis of aquifer performance as a function of parameters such as porosity, transmissibility, and leakage is discussed by Dames and Moore in Refs. 1 and 2. Although such an analysis is beyond the scope of this report, it can be concluded that the well field must contain about 40 wells to be able to simultaneously produce and reinject 2.5–3.2 m^3/sec (4.0–5.0 × 10^4 gpm) of water, which is the flow necessary for air conditioning the airport terminals.

With a 40 well system, the peak flow rate per well is about 575 m^3/hr (2500 gpm). Although such high pumping rates may be attained for large wells (0.91 m or 36 in. diam), it is questionable whether the necessary sustained injection rates of 450 m^3/hr (2,000 gpm) are reasonable.[1] Well clogging and high injection head problems may cause a larger number of wells to be required.

Table 4.1. Properties of the Jameco-Magothy aquifer at each test boring

Boring[a]	Aquifer sub-unit (formation)	Thickness of sub-unit (m)	Estimated range of average horizontal permeability (K_h) of each aquifer sub-unit (m/day)	Estimated range of aquifer transmissibility (T) at each boring (m^2/day)
1	Jameco	8	6.0–14	120–310
	Magothy	18	4.0–11	
2	Jameco	18	22–40	500–930
	Jameco (?)	30	3.0–7.0	
3	Jameco	27	37–55	1100–1700
	Jameco (?)	9	5.0–10	
	Magothy	18	4.5–9.0	
4	Jameco	27	37–55	1200–1900
	Magothy	18	14–21	

[a]See Fig. 3.2 for test well locations.

5. COLD STORAGE SYSTEM DESIGN AND CAPITAL COST ESTIMATION

5.1 Wells and Associated Piping

The well field and accompanying piping systems will be identical for both of the water chilling options previously discussed. The JFK aquifer storage system would need to store and supply about 1.17×10^7 m^3/year (3.1×10^9 gal/year) of 7.2°C water to meet the requirement of the present chilled water system. The well field size has been estimated in Table 5.1, using the aquifer physical parameters indicated. It was assumed that the cold water injection wells would be arranged in a circle which encloses one half of the area needed for cold water storage. The warm water wells were assumed to be in a circular configuration which encloses an area 1.5 times greater than the minimum needed storage area, in order to prevent interaction between the cold and warm wells. This is an oversimplification, but it is sufficient for rough cost estimating purposes.

Table 5.1. Aquifer physical properties and well field size estimates

Average aquifer thickness	45 m
Average aquifer porosity	0.30
Total chilled water to be stored	1.17×10^7 m^3
Aquifer volume required	3.91×10^7 m^3
Land surface area for storage region	8.53×10^5 m^2
Area enclosed by cold water storage wells	4.26×10^5 m^2
Area enclosed by warm water wells	1.27×10^6 m^2

The well field was assumed to be located such that the central heating and cooling facility is near the edge of the cold water injection wells, as shown in Fig. 5.1. This corresponds roughly to the inner ring of wells being located within the terminal parking area (see Fig. 3.2) and represents the minimum piping distance and cost.

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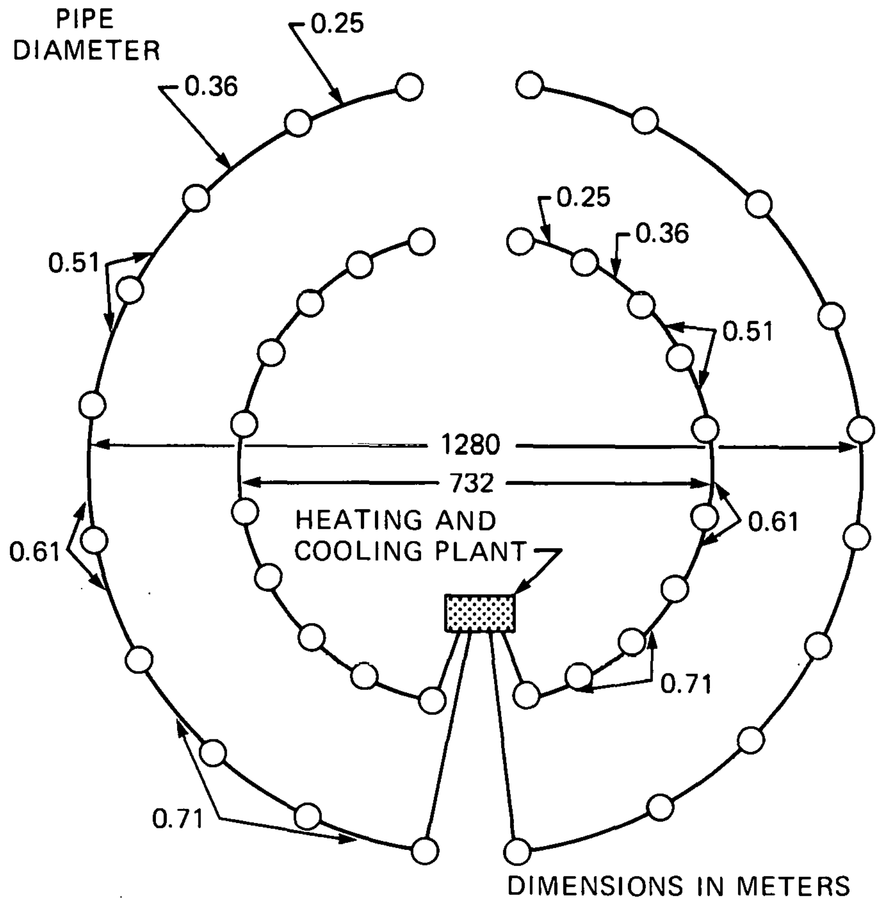

Fig. 5.1. Well field layout.

Cost estimates for the wells and well field piping are given in Table 5.2. A 40-well system was assumed with each well being approximately 0.9 m (3 ft) diam and 110 m (350 ft) deep. Well costs are based on current prices in the New York area as estimated in Ref. 1. Although these costs are much higher than typical well costs elsewhere in the United States, they are typical for the Long Island N.Y., area. The total cost for 40 complete wells with pumps, motors, and testing was estimated at $\$4.6 \times 10^6$. This cost includes test wells, screens, casing, and development.[1]

A detailed breakdown of the well field piping system costs is given in Table 5.3. These system costs were developed using piping and valve

Table 5.2. Well and piping costs

Wells - 110 m (350 ft) deep, 0.9 m (36 in.) diam including screen, casing, development, etc.	$100,000 ea.
Well pump and motor (.150 m^3/sec capacity)	$ 16,000 ea.

Pipe and valve installed cost

Pipe diameter (m)	Pipe diameter (in.)	Total piping cost ($/m)	Total piping cost ($/ft)	Cost per valve ($)
0.25	10	164	50	2200
0.36	14	197	60	4500
0.51	20	216	75	8900
0.61	24	295	90	12500
0.71	28	361	110	16000

Large pipe installed cost[a]

Pipe diameter (m)	Pipe diameter (in.)	Total piping cost ($/m)	Total piping cost ($/ft)	Total piping cost with tunneling ($/m)	Total piping cost with tunneling ($/ft)
0.61	24	492	150	2953	900
0.76	30	722	220	3445	1050
0.91	36	984	300	3937	1200
1.07	42	1312	400	4921	1500
1.22	48	1640	500	5906	1800

[a] Includes return line, insulation, and valves.

costs given in Table 5.2. Piping and valve cost information is based on national average values. However, these estimates are probably low because the cost of labor in the New York area is somewhat higher than the national average, and the airport interference will cause construction difficulties. A total base cost of $\$2.6 \times 10^6$ was estimated for the entire well field piping system. It is probable that additional valves and piping would be needed for the well field; Table 5.3 represents only the minimum possible piping system.

5.2 Heat Exchangers

In both concepts considered in this analysis, heat exchangers are needed to separate the cold capture water from the well water. It has

Table 5.3. Well field piping system costs

Pipe diameter (m)	(in.)	Length required (m)	(ft)	Number of valves	Piping cost ($10^3$$)
		Inner (cold) well piping system			
0.25	10	290	950	20	47
0.36	14	230	750	0	45
0.51	20	460	1500	0	113
0.61	24	460	1500	0	135
0.71	28	920	3000	2	330
				Total	670
		Outer (warm) well piping system			
0.25	10	460	1520	20	76
0.36	14	400	1320	0	79
0.51	20	800	2640	0	198
0.61	24	800	2640	0	238
0.71	28	2160	7080	2	779
				Total	1370
		Complete system costs			
		Total piping costs			$2,040,000
		Total valve costs			150,000
		Alteration of present chilled water system			100,000
		Tunneling costs			300,000
		Total			$2,590,000

been assumed that these would be countercurrent shell and tube heat exchangers. Specifications and cost estimates for the various heat exchangers are shown in Table 5.4. Because of the small temperature difference between the streams, a large heat exchanger surface area is required. For the cooling tower option mild steel is an acceptable material. However the Jamaica Bay system would require a material such as copper nickel alloy to withstand the corrosive nature of the bay water. The estimated cost for just the heat exchangers without concrete work or enclosures is about $\$1.1 \times 10^6$ for either option.

Table 5.4. Heat exchanger specifications, sizing, and cost estimates

	Cooling tower option	Jamaica bay option
Tube size, cm	2.5	2.5
Water velocity (both streams), m/sec	3	3
Fouling factor (both streams), W/m^2-°C	0.066	0.066
Log mean temperature difference, °C	2.8	4.4
Cooling tower loop flow, m^3/sec	2.50	2.50
Aquifer loop flow, m^3/sec	2.50	6.68
Overall heat transfer coefficient, W/m^2-°C	4.5	4.5
Total surface area required, m^2	1.5×10^4	9.3×10^3
Material cost, $/$m^2$		
Steel	75	
Copper nickel		120
Total capital cost, $	1.1×10^6	1.1×10^6

5.3 Cooling Towers

To meet the requirements of the aquifer storage chilled water system, the cooling towers must accommodate water flow rates of 2.5–3.5 m^3/sec (4.0–5.5×10^4 gpm) and chill the water from 10°C to 3°C (50°F to 38°F). The design of such a system would be quite difficult because conventional cooling towers are not designed to operate with near freezing water temperatures and subfreezing air temperatures. Specially designed towers would be needed with a control system to prevent icing and the subsequent damage that may occur.

Rough cost estimates were arrived at with advice from a cooling tower manufacturer. It was optimistically assumed that the 13 existing towers at JFK could be modified to operate as winter chillers at 25% of their 4.9 m^3/sec summer capacity (approximately 1.3 m^3/sec). If a peak capacity of 3.2 m^3/sec is assumed necessary, then 1.9 m^3/sec of water must be chilled in new towers. According to one tower manufacturer, twelve, 6.1-m diam towers would be needed at a total cost of $\$2.1 \times 10^6$. Alteration of the existing towers, special control systems, added excavation, and concrete work would bring the minimum total cost of the cooling tower system to $\$3.0 \times 10^6$.

There is a possibility that the existing towers could not be altered for winter chill capture due to technical difficulties. Also, the new towers may be much more expensive than the given estimate because they must be specially designed to prevent ice damage.

5.4 Jamaica Bay Piping

For the Jamaica Bay case, aquifer water would be transported 1520 m (5000 ft) to a heat exchanger in the bay. The path taken by the piping must cross airport roads, aprons, taxiways, and runways. The existing concrete work cannot be torn up due to the expense and interference with airport operation and therefore tunneling would be necessary. From Fig. 3.2 it is estimated that 760 m (2500 ft) of tunneling would be needed.

An analysis was done to find the optimum pipe size for transporting water to and from the bay area. From Table 5.5 it is seen that 0.9 m (36 in.) piping approximately represents the minimum overall cost. As indicated, the analysis includes inflation of energy costs, indirect and contingency costs, and assumes a 20-year lifetime. Pumping costs were calculated assuming an 80% pump efficiency, and include losses through the heat exchanger system.

Table 5.5 Jamaica Bay piping cost optimization

Pipe diameter (m)	Pipe diameter (in.)	Capital cost (10^6\$)	Water velocity (m/sec)	Head loss (kPa)	Pumping cost (10^6\$)	Yearly adjusted cost[a] (10^6\$)
0.61	24	2.62	8.66	2160	0.352	1.09
0.76	30	3.18	5.55	723	0.118	0.745
0.91	36	3.75	3.84	302	0.049	0.713
1.07	42	4.75	2.83	161	0.026	0.835
1.22	48	5.75	2.16	105	0.017	0.985

Design parameters

Pipe length (one way)	1520 m
Tunneling required	760 m
Water flowrate	2.50 m^3/sec

Cost and economic parameters

Project life	20 yrs
Inflation of energy costs	7%
Interest on bonds	8%
Amortization factor	0.102
Levelizing factor	1.85
Indirect costs	25%
Contingency	30%

[a] Yearly adjusted cost = 0.102 × 1.25 × 1.30 × (capital cost) + 1.85 × (annual pumping cost).

6. OPERATING COSTS

The annual operating costs are comprised of pump and fan power costs and maintenance costs. For the two proposed options, the major difference in annual costs is due to differing power requirements for the cooling towers and the Jamaica Bay piping. The annual cost breakdown is shown in Table 6.1.

Table 6.1. Well and associated piping system pumping costs

Well drawdown and injection head	568 kPa
Piping system average head loss	299 kPa
Well pump and motor efficiency	0.55
Piping system pump efficiency	0.80
Annual volume of circulated water	2.34×10^7 m^3
Electric costs	$0.04/kWhr
Annual well pumping cost	$\$0.27 \times 10^6$
Annual piping system pumping cost	$\$0.10 \times 10^6$

Most of the electric costs were estimated using simple headloss calculations. Table 6.1 gives the electric costs for well pumping and well field piping transmission, with the values used for their calculation. The energy costs of the present chilled water distribution system are known ($140,000/year) and were assumed to be unchanged. The maintenance cost for either option was assumed the same and was estimated from Ref. 2 to be $80,000/year. For the Jamaica Bay option, the electric pumping cost to and from the Bay through 0.91 m (36 in.) pipe (Table 3.5) is $49,000/year. The cost of operating the cooling towers was estimated assuming a 1.8×10^5 Pa (60 ft) head loss in the water system (including some piping and the heat exchangers) and that each tower has a 93 kW (125 hp) fan system which will operate 50 to 60 days per year.

7. ECONOMIC ANALYSIS

The economic analysis is conducted from two view points:

1. What is a winter-chill-aquifer storage project at JFK worth in regard to the potential savings in oil and electricity?
2. What does the proposed system cost?

This analysis assumes that the Port Authority of New York and New Jersey has two options: they can either install a winter-chill system or they can continue operating their present system. Therefore, the investment in the aquifer system must be paid for with the resulting energy savings.

The energy savings from both aquifer storage options are compared with the present air conditioning system in Table 7.1. The present system's oil and electric cost estimates are based on past values supplied by the Port Authority. Both options would realize a savings in energy and energy costs.

Table 7.1. Energy comparison
(All costs in millions of dollars)

	Electric costs[a]	Oil costs[b]
Present system	0.82	.41
Cooling tower option	0.76	
Jamaica Bay case	0.64	

[a] Electric cost = $0.04/kWhr.

[b] Oil cost = $0.132/liter. This value may appear lower than typical fuel oil costs because some natural gas is used.

Table 7.2 presents capital investment and annual cost figures which were used to develop the economic analysis shown in Table 7.3. The high and low contingency values given in Table 7.2, were chosen to reflect the amount of uncertainty, construction interference, technical difficulties, and the high cost of labor in New York City, which are associated with

Table 7.2 Cost analysis

(All costs in millions of dollars)

COOLING TOWER CASE

Capital expenditures

Capital item	Base capital	Contingency (%) Low	Contingency (%) High	Capital with contingency Low	Capital with contingency High
Wells (complete)	4.6	10	20	5.1	5.6
Well field piping	2.6	50	100	3.9	5.2
Heat exchangers	1.1	10	50	1.2	1.7
Cooling towers	3.0	25	50	3.8	4.5
Indirects (25%)				3.5	4.3
Total				17.5	21.3

Annual operating costs

Cooling tower operation	0.17
Well pumping	0.27
Field pumping	0.10
Chilled water distribution	0.14
Additional maintenance	0.08
Total	0.76

JAMAICA BAY CASE

Capital expenditures

Capital item	Base capital	Contingency (%) Low	Contingency (%) High	Capital with contingency Low	Capital with contingency High
Wells (complete)	4.6	10	20	5.1	5.6
Well field piping	2.6	50	100	3.9	5.2
Heat exchangers	1.1	10	50	1.2	1.7
Jamaica Bay piping	3.8	20	50	4.5	5.6
Indirects (25%)				3.7	4.5
Total				18.4	22.6

Annual operating costs

Bay pumping	0.05
Well pumping	0.27
Field pumping	0.10
Chilled water distribution	0.14
Additional maintenance	0.08
Total	0.64

Table 7.3. Economic analysis[a]
(All costs in millions of dollars)

	Annual capital		Levelized operating	Total levelized yearly cost	
	Low	High		Low	High
	5%/yr energy inflation				
Cooling tower option	1.79	2.17	1.17	2.96	3.34
Jamaica Bay option	1.88	2.30	0.99	2.87	3.30
Present system	0	0	2.04	2.04	2.04
	10%/yr energy inflation				
Cooling tower option	1.79	2.17	1.88	3.67	4.05
Jamaica Bay option	1.88	2.30	1.59	3.47	3.89
Present system	0	0	3.30	3.30	3.30
	15%/yr energy inflation				
Cooling tower option	1.79	2.17	3.19	4.98	5.36
Jamaica Bay option	1.88	2.30	2.69	4.57	4.99
Present system	0	0	5.59	5.59	5.59

[a]Assumptions: interest on bonds, 8%; life of project, 20 years; capitalization, 0.102; reference year, 1979.

each capital item. The economic assumptions used (Table 7.3) are applicable to the Port Authority, and because the Port Authority pays no taxes, taxes were excluded from the analysis.

The cost comparison of Table 7.3 is shown for energy price escalation rates of 5, 10, and 15% and a discount rate of 8%. From the table it can be concluded that either option would reach a 20-year break-even point for energy escalation rates between 10 and 15%.

The overall conclusion as to whether the aquifer storage concept is viable compared to the existing cooling system depends largely on the fuel escalation that is projected for the next 20 years. Estimating an inflation rate that will stand the test of time is very difficult in view of the recent increases in fuel price. Figure 7.1 illustrates the erratic nature of fuel prices within the last five years. Two facts seem clear in regard to those prices: prices will probably rise faster than they did

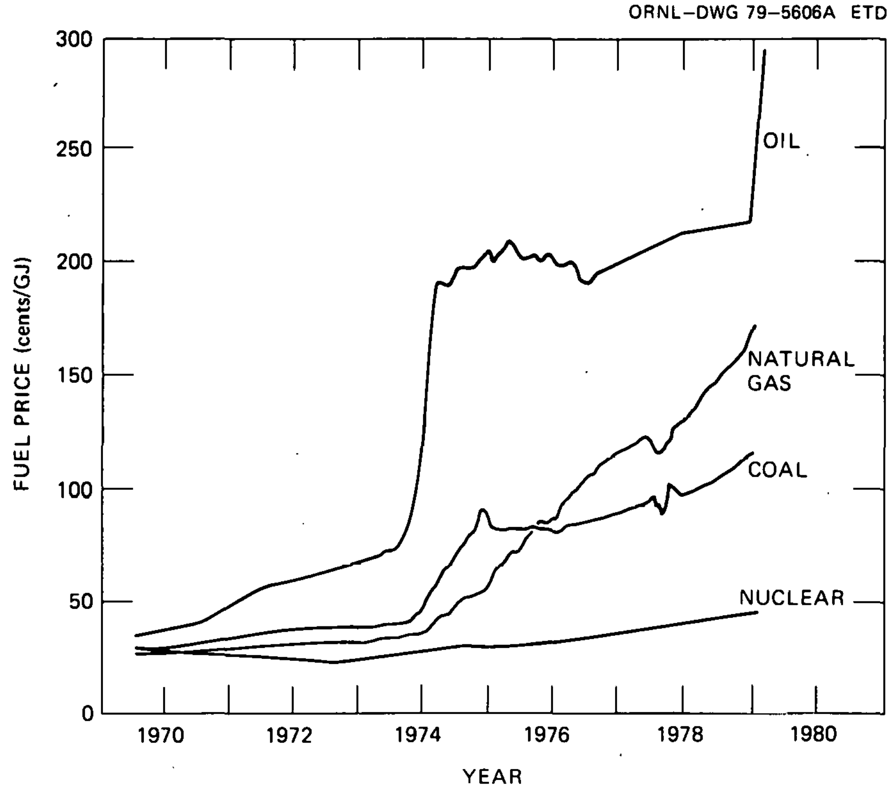

Fig. 7.1. Fuel price escalation.

prior to 1974, and the discontinuities of 1974 and the upswing in 1979 can not be sustained if a viable world economy is to be maintained. It is felt that the best indicator of future prices is the overall increase in cost from 1974, when a realignment of cost to actual value occurred, and the present. This represents an annual escalation of oil and coal prices of about 9%. It is subsequently felt that a sustained escalation in excess of 10% is not forthcoming and the economic analysis should be conducted from that perspective.

Although this preliminary conceptual examination of the chilled water storage concept does not consider changes in all of the design parameters, a few major issues were evaluated in regard to their effect in the overall economics of the storage systems. One design question that has been a major issue, is the need for a second heat exchanger to isolate the air conditioning equipment from the aquifer, as shown in Fig. 7.2. Because the chilled water system must maintain a level of water quality to protect the

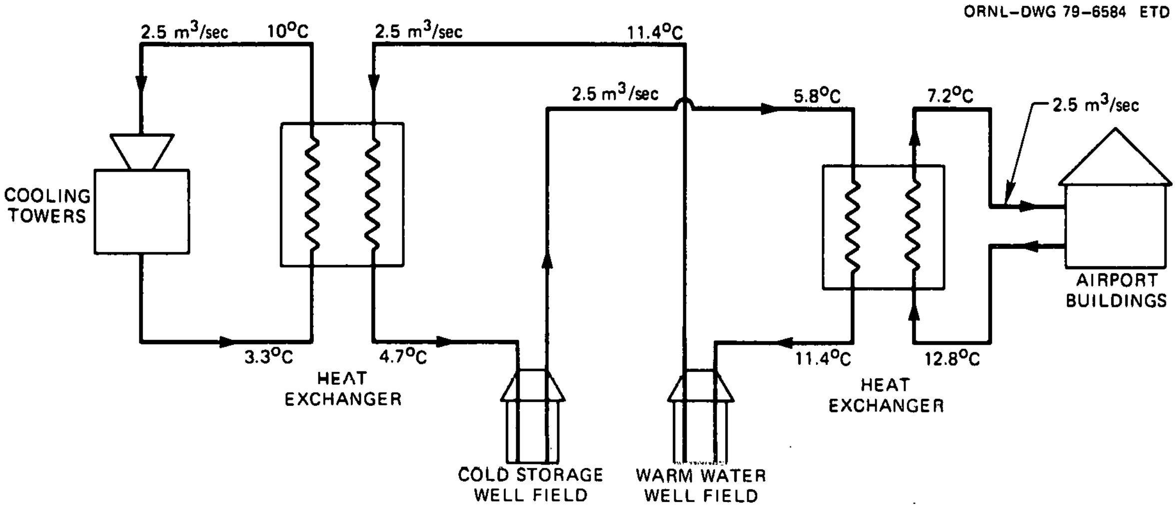

Fig. 7.2. Cooling tower system with second heat exchange loop.

associated equipment, chemical water treatment is needed. A system in which the actual cooling water is discharged into an underground aquifer rules out water treatment because of the exorbitant chemical cost and the possible contamination to the local ground water. Therefore, to protect the airport air conditioning system, a second exchange loop may be necessary.

To accommodate the second heat exchanger and maintain the same delivery temperatures, the approach temperatures must be dropped to 1.4°C (2.5°F) which requires a series of extremely large heat exchangers. For the purpose of this analysis it is assumed that the same set of heat exchangers can be used for cooling the water for the buildings as is used for cooling the water for storage in the aquifer. This assumption is at least reasonable for the cooling tower case since the maximum volumetric flow rates and heat transfer duty are similar for both loops. The Jamaica bay system on the other hand would require that the brackish bay water be pumped to the common exchangers, which may prove to be technically unsound. The original cost estimates assume mild steel is used in all chilled water transmission lines. If the bay water is pumped to the storage area through the underground piping system this raises questions as to the pipe life due to the corrosive action of the water. Corrosion resistant materials or thicker walled pipe may be required to ensure adequate reliability.

The result of adding the second heat exchange loop is indicated in Tables 7.4 and 7.5. While the addition of the second loop changes the total annual levelized cost of the cooling tower system by only 4.5%, the change in the cost of the Jamaica Bay case is nearly 11% and brings both systems to nearly the same overall cost.

Table 7.4. Revised Capital Costs for two loop systems
(All costs in millions of dollars)

	Cooling tower case		Jamaica Bay case	
	Low	High	Low	High
Wells (complete)	5.1	5.6	5.1	5.6
Well field piping	3.9	5.2	3.9	5.2
Heat exchangers	2.4	3.4	4.2	5.7
Cooling towers	3.8	4.5		
Bay piping			4.5	5.6
Indirects (25%)	3.8	4.7	4.4	5.5
Total	19.0	23.4	22.1	27.6

Table 7.5. Effect of design changes[a]
(All costs in millions of dollars)

	Capital		Levelized operating	Total levelized yearly cost	
	Low	High		Low	High
Original cooling tower estimate	1.79	2.17	1.88	3.67	4.05
Revised estimate	1.94	2.39	1.88	3.82	4.27
Original Jamaica Bay estimate	1.88	2.30	1.59	3.47	3.89
Revised estimate	2.25	2.82	1.59	3.84	4.40

[a] Addition of second heat exchange loop, 10% energy inflation assumed.

Some experimental evidence indicates that it is possible, in the case of cooling towers, to inject the water directly into the aquifer without a heat exchange loop, and maintain minimum well pugging. While the method is not implicitly endorsed, it is of some value to understand what a modification of this nature could do for the economics of the system. For comparison, the same design conditions are used as in the base cooling tower case, with the exception that the water is injected directly from the cooling towers. As shown in Fig. 7.3, the water temperature from the wells is assumed to be discharged at 4.4°C (40°F) and returned at 12.8°C (55°F). The costs of this revised system are shown in Table 7.6. Even though this is a rough estimate of the total costs for such a system and several technical issues must be resolved, this approach shows an overall cost saving of greater than 20%.

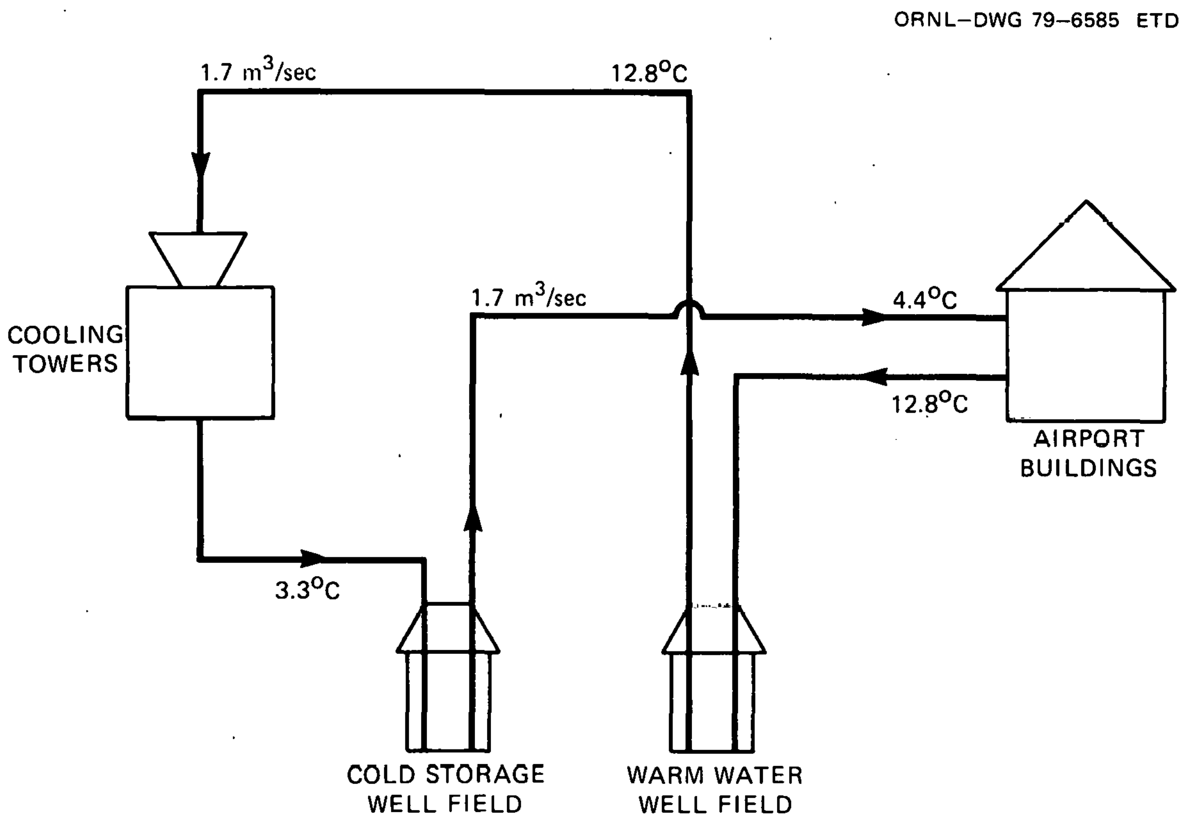

Fig. 7.3. Cooling tower system without heat exchange loops.

Table 7.6. Cost analysis without heat exchangers
(All costs in millions of dollars)

Capital investments	Low	High	Annual operating cost	
Wells	3.6	3.9	Cooling tower operation	0.20
Well field piping	2.8	3.7	Well pumping	0.19
Cooling towers	4.3	5.4	Field pumping	0.08
Indirects	2.7	3.3	Chilled water distribution	0.08
			Additional maintenance	0.08
	13.4	16.3		
				0.63

Cost Comparison
(10% energy inflation)

	Annual capital		Levelized operating	Total levelized yearly cost	
	Low	High		Low	High
Cooling tower options (without heat exchangers)	1.37	1.66	1.56	2.93	3.22
Base case cooling tower option	1.79	2.17	1.88	3.67	4.05
Present system	0	0	3.30	3.30	3.30

8. CONCLUSIONS AND RECOMMENDTIONS

8.1 On Chilled Water Storage Economics

The two aquifer chilled water storage systems evaluated in this preliminary assessment can provide a savings in both energy and energy costs. However, there are insufficient savings to justify the needed capital investment. The addition of a second heat exchange loop increases the annual operating cost of the cooling tower case by 4.5% and the Jamaica Bay Case by 11%. On the other hand, elimination of the heat exchangers can reduce the annualized operating cost by 20%.

8.2 On the JFK Design Concept

It is concluded, based on a reasonable estimate of future energy costs, that the present design concept for storage of winter chill at JFK has insufficient economic incentives. This conclusion is specific to the JFK site and should not be construed as a condemnation of the concept as a whole. It is recommended that if similar projects are pursued a rethinking of the design be initiated to simplify the system and incorporate modifications in which the heat exchange loops can be eliminated.

8.3 On Future R&D Needs

Development ot a system that can operate reliably without any heat exchange loops should be a primary goal of the aquifer storage R&D program. It is recommended that further research similar to the direct injection method being used at Texas A&M University be considered.

It is concluded that design of a reliable storage system that can eliminate any heat exchange loops substantially improves the economic incentives for the concept and should be a major goal of DOE's R&D program.

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1. Dames and Moore, "Hydrogeological Conditions at JFK Airport and an Analysis of Aquifer Properties Affecting Performance of the Proposed Aquifer Cold-Water Storage Project at the Airport," prepared for Desert Reclamation Industries, Plainfield, N.J., (May 1978).

2. Dames and Moore, "Report on Exploratory Drilling Program at JFK Airport, Long Island, New York," prepared for Desert Reclamation Industries, Plainfield, N.J. (January 1979).

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