POTENTIAL WATER AND ENERGY CONSERVATION AND IMPROVED FLEXIBILITY FOR WATER USERS IN THE OASIS AREA OF THE COACHELLA VALLEY WATER DISTRICT, CALIFORNIA

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ABSTRACT

The Oasis Area of the Coachella Valley Water District (CVWD) consists of approximately 12,000 acres of farmland with 220 water users. Approximately 50,000 acre-feet of Colorado River water are delivered to the area annually. Water is conveyed from the Coachella Canal across the valley in a single irrigation lateral. Once in the Oasis Area, the water enters a small storage tower where it is distributed to 4 sublaterals. All pumps operate off of 2 of the sublaterals which lift 10,000 acre-feet of water annually to 2,000 acres of land. Approximately 265 acre-feet of regulatory discharge and operational spillage occur annually from regulatory meters at the ends of the laterals or from the tower overflow.

A study was conducted by JMLord, Inc. to determine the feasibility of improvements to the Oasis Area distribution system of CVWD. Recommended improvements were selected based on their ability to provide water and energy conservation and to increase flexibility in water ordering by, and delivery to, water users within operational limits.

The basis of the Feasibility study of the Oasis system provides a discussion and recommendation for the following:

1. Improving efficiencies of the seven (7) booster pump stations;
2. Replacing/upgrading water distribution controls at each of the seven (7) booster pump stations to facilitate improved leak detection and to increase flexibility in water ordering by, and delivery to, water users within operational limits;
3. Constructing an operating spill and regulatory recovery systems, which includes associated collection, conveyance and pumping facilities; and
4. Automating the distribution system.

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The overall benefit cost ratio of recommended improvements was 1.90 with an annualized cost of $78,743 and an annual benefit of $149,610. Recommended improvements include upgrading six of seven pump stations with variable frequency drives and SCADA controls, connecting regulatory meters to existing farm reservoirs and installation of flow meters, and construction of a regulating reservoir with a high water elevation equal to that of the tower.

PREAMBLE

This study was funded under the California Safe Drinking Water, Clean Water, Watershed Protection, and Flood Protection Act, Agricultural Water Conservation Program, the State of California Department of Water Resources (DWR), Contract No. F63103.

The purpose of the study was to determine the feasibility of improvements to the Oasis Area distribution system of the Coachella Valley Water District (CVWD). Recommended improvements were selected based on their ability to provide water and energy conservation and to increase flexibility in water ordering by, and delivery to, water users within operational limits.

BACKGROUND

Pumping Systems

Pump stations, called O-pumps, in the Oasis area are dual parallel or single pump systems. These pump systems lift 10,000 acre-feet of water annually to 2000 acres of agriculture land. The annual pumping cost for the O-Pumps is estimated to be $130,000. Thus the average pumping cost per acre-foot of water is around $13.00. The daily demand at each O-Pump station ranges from 0 to 15 cubic feet per second (cfs) depending on the particular pump station and daily water orders.

The pumping cost analysis indicated that a significant amount of energy is consumed annually due to losses in manual control valves downstream of the pumping systems (estimated at $61,710 in energy loss). Control valves are "throttled" to match pump flows. Energy consumption may be minimized by matching the head produced by the pumps to system requirements over the range of demand flows and by maximizing overall pumping plant efficiency.

Alternative considerations include replacement of the current pump systems with pump systems matched to the delivery system head/demand profiles (thereby minimizing throttling). Alternatives considered are:

1. Two pumps of the same size
2. Two pumps, one small for low volumes, one large for high volumes
3. Replace one of the pumps with a Variable Frequency Drive (VFD) pump

Tower System

The Oasis Tower is an unsealed cylindrical tank, approximately 50 feet in height. The water surface elevation in the tower is controlled by adjusting the radial and check gates at the Coachella Canal and by adjusting the distribution gates at the base. The water surface elevation in the tower is regulated over a range of approximately 3 feet. In order to prevent spillage from the tower, the maximum water level is not exceeded. The minimum water surface elevation is maintained to reduce the risk of the O-1, O-3, and O-4 pumps losing suction. Typically, the water surface elevation is maintained at 0.5 – 1.5 feet below the maximum water level. The wasteway from the tower was determined to have a capacity of 30 cfs. Excess flows to the tower above 30 cfs are expected to result in overtopping of the tower.

The Oasis Tower acts as the distribution point for water deliveries to the Oasis Distribution System. The daily flow to the tower is controlled at the Coachella Canal. Adjustments at the canal require 15 minutes before the impact reaches the tower. Storage capacity of the tower is virtually non-existent.

Due to the amount of time required for flow adjustments at the canal to impact the Oasis Distribution System, it would be desirable for the Oasis Tower to provide some storage to account for differences in the amount of water supplied by the canal and the amount distributed through the Oasis system at any given time. Of particular concern is that starting/stopping the O-Pumps simultaneously could result in significant drawdown or discharge within the tower. In such an event, the available storage of the tower fails to compensate for possible excess supply from the canal. Excess water, which overflows the tower, could cause the tower to collapse due to erosion at the base and/or flooding of nearby areas. The analysis presented here provides insight into the effect of starting/stopping pumps simultaneously on the water level in the tower.

Regulatory Discharge Systems

There are six regulatory flow meters throughout the Oasis system. These meters are used solely for regulatory discharge, they are not capable of providing normal canal water service to growers. System upgrades to allow for the capture and/or elimination of regulatory discharge are investigated.

METHODS

Pump Systems Analysis

The pump systems analysis was performed to find ways of minimizing electrical consumption for each O-Pump station. Replacement pumps or VFDs were selected that match the system head requirements and demand profile as closely as possible. Pump line performance curves and operating strategies that minimize electrical consumption were generated for several alternatives.

Pump performance curves relating flow to head for each O-Pump station were developed from multi-point pump test. For pump stations with two pumps operating in parallel, a pump performance curve relating head to flow for the two pumps operating simultaneously was also developed. A sample plot showing two pump performance curves and the curve resulting from operating both pumps in parallel is shown in Figure 1.

Note that the curve relating overall pumping plant efficiency (OPPE) to flow is a combined curve representing the OPPE over the full range of flows that can be provided by each pump. In the first portion of the curve, the small pump (Pump #1) is run. In the middle region, the large pump (Pump #2) is run. In the third region, both pumps are run to satisfy flow and head requirements.

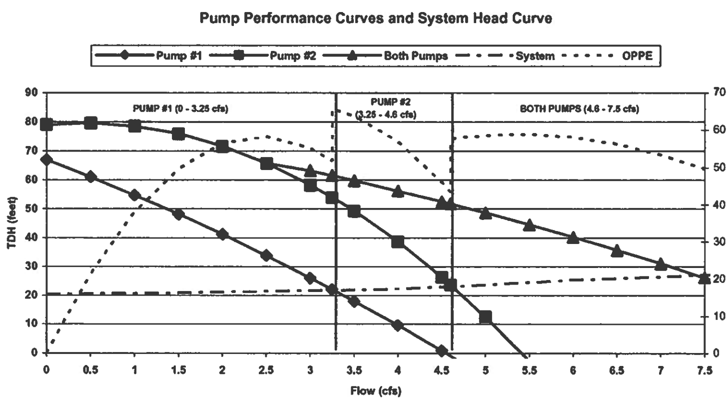

Figure 1. Sample Pump Performance Curves

The system head curve in addition to the pump performance curves is also shown in Figure 1. The system head curve provides the head required to satisfy the lift requirements and pressure losses of the system at a given flow. The three regions of operation are developed by finding the flow at which the head produced by the pump is equal to the system head requirements. A system head curve was generated for each pump station using the Hydraulic Model of the Oasis Area Distribution System.

Replacement pumps were selected to provide at least 120% of the required system head for their range of operation. The 20% factor of safety should account for pump wear, uncertainty of the system head requirements, and uncertainty of the maximum demand at each pump station.

Pump selection design points were selected to ensure adequate delivery capacity and to minimize pumping costs. Historic demand distributions and system head requirements define the minimum requirements of the pumps. Best efficiency or "design" points were selected based on the average flow within each pump's operating range.

The average rate for all pumping plants and the Oasis Tower was $0.085 per kilowatt-hour (based on power records for year 2000). Comparing the expected energy consumption of each alternate to current consumption provided an estimate of savings expected.

Costs estimates to implement the Replace Pumps or VFD additions were provided based on the design points determined for replacement pumps. Additional costs include the addition of a pressure sensor, a flow sensor and SCADA Programming.

Changes in annual operation and maintenance requirements were estimated for the install VFD alternative only. Because a VFD requires cooling, energy used by the air conditioning unit was added as an increase to the annual energy cost.

The VFD is equipped with a PLC to control the speed of the pump and motor electronically. The difference in operation is that no manual throttling is required by the operator to achieve the desired head. This decreases the time at the pump station, which translates to reduced vehicle wear and gas use. Since the flow can be controlled remotely, it also reduces personnel hours.

The total capital cost of the improvement was divided by ten to determine the amortized cost of the improvement. For each improvement alternative, the annual implementation cost was calculated by adding the amortized cost of the improvement to the increased annual maintenance cost.

Benefit-cost ratios of each alternative are calculated by dividing the projected annual pumping cost savings by the annualized implementation cost of the improvement. Alternatives with benefits exceeding costs (benefit-cost ratio > 1) were considered viable.

Tower Analysis

Minimization of regulatory discharge is the primary goal of changes to the tower system. The cost of water was estimated to be $60 per ac-ft. The annual regulatory waste from the tower operations is 15 ac-ft. Therefore, the expected annual watersavings is $60 per ac-ft x 15 ac-ft per year, or $900.

The Oasis Tower was modeled by examining USBR drawings of the structure, which specify tower size and shape. The drawings also provide maximum, normal, and minimum water surface elevations. District employees familiar with the Oasis system have provided further insight into the operation of the tower, the operation of the 97.1 lateral and canal gates, and the effect of tower water levels on the operation of the O-Pumps.

The daily flow through the Oasis Tower to the distribution system ranges from 0 to 135 cfs, with an average flow of 65.4 cfs and a standard deviation 28.4 cfs. Approximately 50,000 acre-feet of water are delivered each year through the 97.1 lateral to the Oasis Distribution system.

The maximum expected flow to the O-Pumps was calculated from the average and standard deviations of the daily flow to the O-Pumps of the 97.1-7.1W lateral. The maximum flow was calculated as the average flow plus 3 standard deviations.

The relationship of the change in water level in the tower to the amount of time elapsed after the pumps start is provided in Equation 1.

$$dh/dt = [Q_{in}(t) - Q_{out}(t)] / A \qquad \text{[EQ 1]}$$

Where,

- dh/dt = change in water surface elevation within the tower per unit time in units of feet per second.
- $Q_{in}(t)$ = flow into tower at time, t, in units of cubic feet per second.
- $Q_{out}(t)$ = flow out of tower at time, t, in units of cubic feet per second.
- t = time elapsed relative to pumps starting in units of seconds.
- A = cross-sectional area of tower in units of square feet.

Note that if $dh/dt > 0$, the tower will fill. If the water level reaches the maximum water surface elevation, the excess flow to the tower is diverted to the wasteway. Once the water begins to spill from the tower, it is assumed that the water surface elevation in the tower remains constant at the maximum value.

Assuming that the gravity-fed portion of the distribution will perform exactly the same regardless of the O-Pumps, the portion of the flow into the tower that supplies the gravity-fed portion of the system may be neglected. Thus, $Q_{in}(t)$ may be defined as the flow into the tower designated for the O-Pumps, and $Q_{out}(t)$ may be defined as the flow out of the tower to the O-Pumps.

Equation 2 was integrated to provide the water surface elevation in the tower as a function of time.

$$h(t) = 1/A\ [Q_{in}(t) - Q_{out}(t)]dt + h_0 \quad h_{min} < h < h_{max} \qquad \text{[EQ 2]}$$

Where,

- $h(t)$ = water surface elevation in tower at time, t, in units of feet.

h_0 = initial water surface elevation in tower at time, t, in units of feet.
h_{min} = minimum water surface elevation at which pumps lose suction in units of feet..
h_{max} = maximum water surface elevation at which tower begins to overflow, in units of feet.

When the water in the tower drops below the minimum water surface elevation, the O-Pumps of the 97.1-7.1W lateral are assumed to lose suction and stop pumping. Thus, Q_{out} drops to 0 cfs.

The flows into and out of the Oasis Tower were modeled as step functions, assuming that the pumps start pumping at full flow, and that the individual flows through each pump impact the tower at the same time. The increased supply from the canal reaches the tower as an instantaneous increase in flow.

In reality, changes in flow within the system occur more gradually. Pumps may be started at low flow and the flow gradually increased by opening control valves downstream of the pumps. Additional flow is not released from the canal all at once, rather it is gradually increased until the desired flow is supplied.

The time that increased flow from the canal reaches the tower is a function of the time at which the canal gates are operated and the time required for flow released from the canal to reach the tower. For purposes of this analysis, 15 minutes is used as the time it takes for increased flow from the canal to reach the tower.

Adding a reservoir with a high water elevation equal to the overflow tower elevation would reduce or eliminate spillage and risk of tower failure while preventing loss of service to water users. Further, the reservoir could be located to provide groundwater recharge as a secondary benefit. The water could percolate or be pumped back (or backflow by gravity) into the tower when needed. Adding a reservoir to the system would virtually eliminate the approximately 15 ac-ft of regulatory water that is currently lost annually.

A cost estimate to construct and install a reservoir system was provided based on the reservoir system operational characteristics. The amortized cost was estimated by assuming a useful life of 10 years. The total capital cost of the improvement was divided by ten to determine the amortized cost of the improvement.

Regulatory Meter Analysis

Avoidance of regulatory discharge is the primary goal of changes to the regulatory system. The cost of water was estimated to be $60 per ac-ft. The annual regulatory waste through the regulatory meters is 300 ac-ft. Therefore, the expected annual savings is $60 per ac-ft x 300 ac-ft per year, or $18,000.

Existing farm reservoirs could be used to help store and utilize regulatory discharge water. This would be a win-win situation for both the grower and the District. The District would minimize regulatory discharge, save the initial cost and annual maintenance of a new reservoir, and save the cost and maintenance of a pump-back system. The grower would receive "excess" canal water periodically at no charge, which in turn would provide water savings to the District. The overall effect would be to effectively eliminate this small regulatory discharge. The analysis focused on identifying existing reservoirs to be used for each of the six regulatory meters.

A cost estimate to construct and install pipe stands with baffles was provided based on the pipe stand/baffle design. The amortized cost was estimated by assuming a useful life of 10 years for the upgrades. The total capital cost of the improvement was divided by ten to determine the amortized cost of the improvement. The regulatory meter sites require a flow sensor and a pipe stand with baffle.

RESULTS

Pump Systems

The Benefit-Cost results of the pump improvements are provided in Table 1. The alternative to install a VFD generally provided the greatest benefit-cost ratio. Based on the results, upgrades to 6 of the 7 pumps stations (O-1, O-3, O-4, O-5, O-6 and O-7) with Variable Frequency Drives and the associated sensor instruments and SCADA upgrades were recommended.

Tower System

The tower analysis showed that the time required for the tower to begin spilling into the wasteway is 2.59 seconds and the cumulative discharge from the tower is 24,000 ft^3 or .56 ac-ft. Therefore, for each event, approximately 0.56 ac-ft regulatory discharge can be expected due to lack of tower storage, indicating the need for additional tower storage.

Table 1. Benefit-Cost Ratios of Improvement Alternatives

Pump System	Alternative	Projected Savings	Annual Implementation Cost	Benefit-Cost Ratio
O-1	Replacement with Two Identical Pumps	$3,880	$3,240	1.20
O-1	Replacement with Two Different Pumps	$8,820	$2,960	2.98
O-1	Installation of VFD, Pump #2	$20,040	$3,650	5.49
O-2	Replacement with Two Identical Pumps	-$1440	$2,370	-0.61
O-2	Replacement with Two Different Pumps	-$300	$2,415	-0.12
O-2	Installation of VFD, Pump #2	$1,220	$2,680	.46
O-3	Replacement with Two Identical Pumps	$4,091	$3,150	1.30
O-3	Replacement with Two Different Pumps	$6,857	$3,045	2.25
O-3	Installation of VFD, Pump #1	$8,860	$3,650	2.43
O-4	Replacement with Two Identical Pumps	$3,240	$3,910	0.83
O-4	Replacement with Two Different Pumps	$12,780	$3,605	3.55
O-4	Installation of VFD, Pump #1	$18,940	$4,235	4.47
O-5	Replace Pump	-$4,740	$1,275	-3.72
O-5	Installation of VFD	$1,560	$1,500	1.04
O-6	Replace Pump	$3,770	$1,150	3.28
O-6	Installation of VFD	$9,000	$2,850	3.16
O-7	Replacement with Two Identical Pumps	$2,240	$2,200	1.02
O-7	Replacement with Two Different Pumps	$4,980	$2,180	2.28
O-7	Installation of VFD, Pump #1	$1,800	$1,320	1.36
O-7	Installation of VFD, Pump #2	$3,310	$1,700	1.95

Regulatory Meter

Farm reservoirs were identified near 5 of the regulatory meters. Using these results, of the 300 ac-ft total discharge, approximately 250 ac-ft of regulatory water could be eliminated.

Benefits and Savings

Benefits to be achieved include: (1) Increased level of service to water users, (2) Reduced wear and increased pump efficiency, (3) Reduction in vehicle wear and fuel use, (4) Reduction in labor costs, (5) Reduced stress on operational personnel, (6) Energy savings, (7) Water savings and (8) Costs may be recouped within 5 years.

Total annual savings for energy, water, equipment and labor due to the recommended changes are provided in Table 2. This table presents the total annual savings of $149,610.

Table 2. CVWD Annual Savings

Item	Energy	Water	Equipment	Labor	Total
O-1 Pumps	$20,040		$2,000	$10,000	$32,040
O-3 Pumps	$8,860		$2,000	$10,000	$20,860
O-4 Pumps	$18,940		$2,000	$10,000	$30,940
O-5 Pump	$1,560		$2,000	$10,000	$13,560
O-6 Pump	$9,000		$2,000	$10,000	$21,000
O-7 Pumps	$3,310		$2,000	$10,000	$15,310
Regulatory Meters		$15,000			$15,000
Tower		$900			$900
Total	$61,710	$15,900	$12,000	$60,000	$149,610

Annual Cost

Total costs for equipment and installation cost are summarized in Table 3. The total cost is $ 733,445.

Note that another cost that must be considered is the cost of project management and integration. This is estimated to be 7.5% of the total program costs. This includes the detailed in-house design, development of the RFP, integration, inspection, and project administration.

The annual amortized costs of the program are presented in Table 4. The total yearly cost is $ 78,743. Annual savings vs. annual amortized cost is shown in Table 5. The yearly net savings is $70,867.

Simple payback years then (calculated as the total equipment and installation costs divided by the total annual savings) is 4.9 years. The overall benefit-cost ration is 1.90. These results indicate that it is feasible to proceed with the recommended improvements.

Table 3. Total Equipment and Installation Cost

Item	VFD Equip & Install	Meter & Reservoir Install	Distributed SCADA Programs	Sensor Equip & Install	Project Cost (7.5%)	Total
O-1 Pumps	$27,500		$1,000	$13,100	$3,120	$44,720
O-3 Pumps	$27,500		$1,000	$13,100	$3,120	$44,720
O-4 Pumps	$33,350		$1,000	$13,100	$3,559	$51,009
O-5 Pump	$6,000		$1,000	$7,645	$1,098	$15,743
O-6 Pump	$19,500		$1,000	$13,100	$2,520	$36,120
O-7 Pumps	$8,000		$1,000	$7,645	$1,248	$17,893
Meters		$36,735			$2,755	$39,490
Tower		$450,000			$33,750	$483,750
Total	$121,850	$486,735	$6,000	$67,690	$51,170	$733,445

Table 4. Annual Amortized Cost

Item	Annualized EQ & Installation Cost	Additional Annual Maint/Ops Expenses	Annual Cost
O-1 Pumps	$4,472	$900	$5,372
O-3 Pumps	$4,472	$900	$5,372
O-4 Pumps	$5,100	$900	$6,000
O-5 Pump	$1,574	$900	$2,474
O-6 Pump	$3,612	$900	$4,512
O-7 Pumps	$1,789	$900	$2,689
Regulatory Meters	$3,949		$3,949
Tower	$48,375		$48,375
Total	$73,343	$5,400	$78,743

Table 5. Annual Benefit vs. Cost

Item	Annual Savings	Annual Cost	Difference	B-C Ratio
O-1 Pumps	$32,040	$5,372	$26,668	6.0
O-3 Pumps	$20,860	$5,372	$15,488	3.9
O-4 Pumps	$30,940	$6,000	$24,940	5.2
O-5 Pump	$13,560	$2,474	$11,086	5.5
O-6 Pump	$21,000	$4,512	$16,488	4.7
O-7 Pumps	$15,310	$2,689	$12,621	5.7
Regulatory Meters	$15,000	$3,949	$11,051	1.4
Tower	$900	$48,375	-$47,475	0.02
Total	$149,610	$78,743	$70,867	1.90