Water for a Sustainable World — Limited Supplies and Expanding Demand

Second International Conference on Irrigation and Drainage

Phoenix, Arizona
May 12-15, 2003

Sponsored by

U.S. Committee on Irrigation and Drainage

Edited by

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Agricultural Research Service, USDA
Susan S. Anderson
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Published by

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INITIAL DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR OPERATING A LATERAL INTERCEPTOR RESERVOIR SYSTEM

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ABSTRACT

Interceptor reservoirs and systems constructed under the Imperial Irrigation District/Metropolitan Water District Water Conservation Program (Program) have enabled dramatic reductions in lateral spillage. However, infrequently the reservoirs cannot contain all of the intercepted lateral spillage, resulting in reservoir spillage.

A spreadsheet-based simulation model was developed to evaluate alternative operation scenarios and physical improvements to the reservoirs. Simulations based on 46 months of historical intercepted flows and downstream demands showed that operational improvements alone offered the potential to reduce spillage from the historical base of 3,076 (1.7 percent of intercepted flow) to about 1,050 acre-feet.

Additional simulations showed that enlarging reservoir outlet capacity had little effect on reducing spillage, but that spillage could be eliminated by adding 465 acre-feet of storage capacity. Simulations also tested the sensitivity of reservoir spillage to intercepted flow increases. Even with the operational improvements, a 20% increase in intercepted flows would cause spillage to increase from simulated levels of 1,050 to 6,404 acre-feet. These conditions required more than 3,000 acre-feet of additional reservoir capacity to eliminate spillage.

The conclusion derived from the analysis and simulations is that relatively inexpensive operational improvements are preferable to costly capital improvements for reducing spillage. Development of a decision support system (DSS) to institutionalize the operational logic developed from the model simulations is underway.

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BACKGROUND

Imperial Irrigation District (IID) has constructed six regulating reservoirs and four interceptor reservoirs as components of the IID's water delivery system. Regulating reservoirs are used to absorb mismatches between water demands and available supply. They are typically operated near their mid-storage point, allowing them to absorb surpluses or fill deficiencies, as needed. In contrast, interceptor reservoirs have been planned to receive spillage and operational water from upslope laterals, and provide that water, as scheduled, to downslope portions of the system. Interceptor reservoirs should be operated to evacuate the previous day's intercepted flows, subject to the limit of downstream demand, to maximize the reservoir capacity available to receive the current day's flows.

Infrequently, the interceptor reservoirs, built to conserve water by the Program, gradually fill, and eventually spill intercepted water. Although the spillage from the interceptor reservoirs is less than two percent of the total volume intercepted, this spillage counts directly against the Program savings. Thus, in terms of the savings, reducing this spillage is important.

This study focuses on the Vail Canal service area, where there are three interceptor reservoirs (Russell, Willey and Young) that are operationally linked (Figure 1). The purposes of this study were to determine the causes of the operational problems described above and formulate alternative solutions. All work was performed in close cooperation with IID staff, particularly main system operators. This paper is organized into five sections: Current Operations, Historical Analysis, Model Approach and Structure, Operational Analyses, Recommended Daily Operations Criteria and Conclusions.

CURRENT OPERATIONS

Operational Goals

Water system operators have three basic goals listed below in order of decreasing importance:

1. Meet grower demand,
2. Accept all water ordered from Lake Mead, and
3. Operate efficiently (minimize spillage).

These goals must be met within the physical constraints of the system. The operators have been able to decrease the amount of spillage in recent years due to the reservoirs and other system improvements, without reducing customer service.

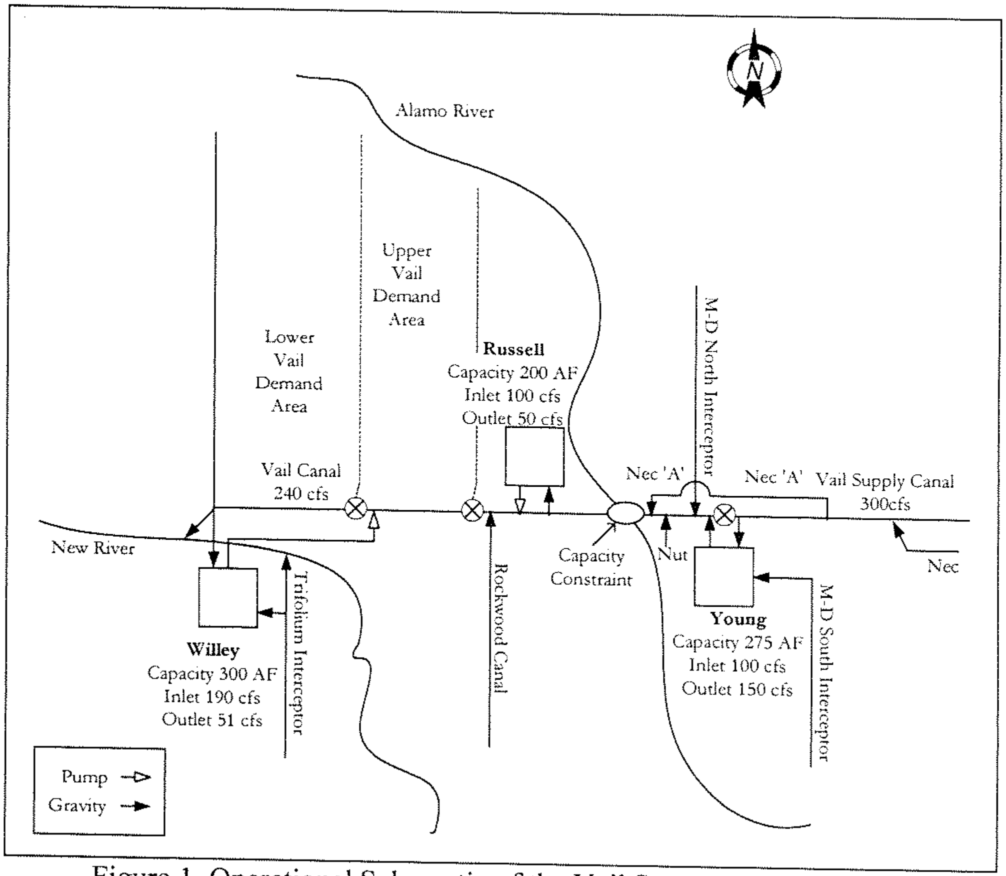

Figure 1. Operational Schematic of the Vail System Service Area.

Operational Plans

IID system operations have evolved over the years. Reservoirs have been added to the canal system one by one over the last 25 years driven by the need to shorten flow transit times and minimize fluctuations. When a reservoir is added, an operations plan is developed for the IID system operators. They adapt these plans while integrating them into the operation of the entire system.

The water dispatcher follows general guidelines when setting up the next day's operational plan. The water dispatcher reviews current conditions and trends, and then applies the general guidelines and his judgment to formulate the next day's operational plan. To preserve operational flexibility, operators prefer to release 5-10 cfs less than the available reservoir outlet capacity. This provides the flexibility to bring in water immediately by increasing reservoir releases.

The three reservoirs in the Vail System are interceptor reservoirs built to store flows intercepted by the lateral interceptor systems. The operations goal is to keep interceptor reservoirs between 25% and 50% full, so the reservoir has storage available to capture lateral interceptor flows.

HISTORICAL ANALYSIS

Beginning with 1998 (startup of the Trifolium Interceptor), historical data were reviewed, concentrating on periods of operational spillage from reservoirs. Emphasis was placed on analyzing reservoir spillage patterns and their relationship to reservoir inflow and downstream demand. These characteristics indicate the magnitude and, potentially, the causes of operational problems. Additionally, they are instructive in outlining simulation scenarios.

Spillage

The focus of this study is on reducing the spillage at the interceptor and main canal spillage sites, which include: (1) Trifolium Interceptor Spill, (2) Vail Canal Spill and (3) Vail North End Dam Spill. The total annual spillage at these sites fell from about 1,150 acre-feet in 1998 to about 350 acre-feet in 2000 with the bulk of the reduction occurring at the Trifolium Interceptor Spill (Figure 2). This indicates that the operators are learning how to better manage the system to minimize spillage. However, due largely to increased spillage at Vail North End Dam, the total spillage had rebounded to about 775 acre-feet through October 31, 2001. The bulk of this increase occurred in March and may have been related to rainfall; it is considered to be an anomaly.

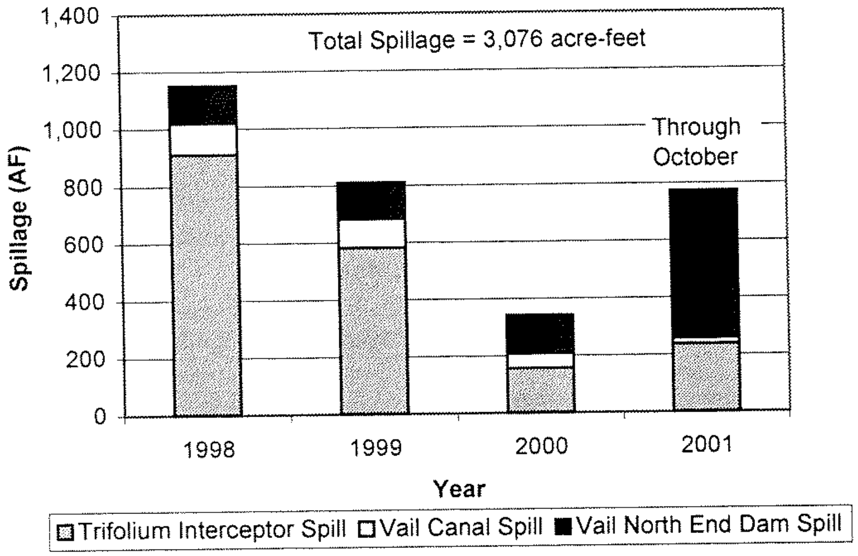

Figure 2. Historical Annual Spillage from the Interceptors and Main Canals Associated with the Vail System (January 1998-October 2001).

Monthly averages reveal that most of the spillage at the interceptor and main canal spillage sites occurs in the months of October, December, January, February and March (Figure 3).

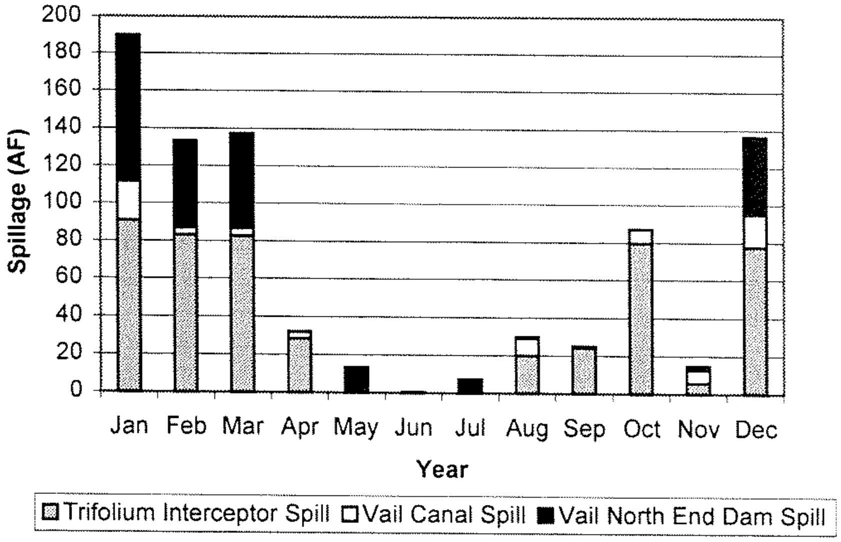

Figure 3. Historical Monthly Average Spillage from the Interceptors and Main Canals Associated with the Vail System (January 1998-October 2001).

Intercepted Inflows

Discharges from the Trifolium, Mulberry-D North and Mulberry-D South Interceptors and the Rockwood Canal are captured and stored in the Willey, Russell and Young Reservoirs. Total gross intercepted volume has increased 15 percent from about 42,800 acre-feet in 1998 to about 49,400 acre-feet in 2000.

September, October, November and December are the months with the greatest average intercepted flows. This seasonal increase is greatest in the Trifolium Interceptor, where the average flow in these four months is nearly 44 percent greater than in the remaining eight months.

Demand

Intercepted flows are re-regulated in the interceptor reservoirs and used to serve demand in the Vail System. The portion of the Vail System that can be supplied from the Willey Reservoir is designated as the Lower Vail demand area. The remaining deliveries are part of the Upper Vail demand area.

The total annual demand for the entire Vail System and for the individual Lower and Upper Vail demand areas has remained essentially constant from 1998 through 2001 at about 107,850 acre-feet. Demand in the Vail System is highly seasonal with the average monthly demand for November through February about half (5,600 versus 10,800 acre-feet) that of the rest of the year.

Synthesis

Spillage from Vail System interceptors and main canals can be expected when either of the following situations persist: (1) demand is less than the intercepted inflow or (2) the intercepted flow is greater than the reservoir outlet capacity. For the Willey Reservoir, the six-month period of September through February emerges as a critical period where there is little margin for operational error if spillage is to be avoided. The highest intercepted flows coincide with the lowest demand in these months. These are the months when most of the spillage from the interceptors and main canals has occurred.

MODEL APPROACH AND STRUCTURE

A spreadsheet model was developed to analyze historical reservoir/system operations and to test alternative operations strategies. The model maintains mass-balance of water on a daily time step and simulates reservoir operations using actual historical data. The model was used to identify and test alternative operations protocols and priorities that seek to reduce reservoir spillage while maintaining or enhancing the levels of delivery flexibility provided to growers. The model is capable of examining the effects of changes in delivery flexibility, through modification of reservoir inflow series.

Model Structure

The simulation is divided into four parts, one for each interceptor reservoir and one for the Vail Supply Canal. A control page allows physical and operational criteria used in the simulation to be changed.

User-Variable Simulation Parameters

The following physical operational parameters can be uniquely specified for each reservoir:

1. Interceptor Inflow Multiplier (%) - two seasonal values
2. Pump Capacity (cfs) - two seasonal values
3. Reservoir Minimum Storage (af) - two seasonal values
4. Reservoir Maximum Storage (af)
5. Reservoir Loss (cfs)
6. System Loss (cfs)
7. Reservoir Storage at Start of Simulation as percent of Maximum Storage
8. Anticipated Intercepted Flow - two seasonal values

OPERATIONS ANALYSES

The objective is to develop operational rules for planning releases from the reservoirs in the Vail System. With respect to the first two operational goals of meeting grower demand and accepting all water ordered and released from Lake Mead, these rules are expected to perform as well as present operations. Clear, concise rules for planning reservoir releases are expected to result in further spillage reduction. The evaluation criterion is the total spillage from the interceptor reservoirs associated with the Vail System.

Operations Versus Capital Improvements

The historical analysis identified two operational problems in the Vail System that cause accumulating storage in the reservoirs. First, on some days the intercepted flows exceed the downstream demand. Second, on some days the intercepted inflow to the Willey Reservoir exceeds the release capacity. This study explored operations improvements to minimize the spillage. However, to explore the full range of alternatives increased reservoir storage and pumping capacity alternatives were also developed.

The baseline historical simulation with consistent planning logic reduced the total spillage over 46 months simulated from 3,076 to 1,750 acre-feet (43%) (Table 1). Anticipating inflows further reduced spillage to 1,390 acre-feet. The minimum spillage achievable under historical inflow conditions by increasing reservoir outlet capacity is 1,659 acre-feet. This requires increasing the Willey Reservoir outlet pump capacity by 10 cfs from 50 to 60 cfs and no changes at Russell and Young Reservoirs. Assuming historical intercepted flows and consistent planning logic, spillage can be reduced to zero by increasing the reservoir storage capacity by 150, 5 and 310 acre-feet at Willey, Russell and Young Reservoirs, respectively.

A 20% increase in historical inflows will increase spillage or the storage required about 300% under all options. Improved operation clearly has more potential for reducing spillage under the historical flow conditions compared to increasing the reservoir release capacity. Thus, additional refinements, suggested by the data review were explored with the objective of further reducing the spillage of the improved operations alternative.

Improved Operations Criteria Development

Three factors affect reservoir releases: (1) downstream demand, (2) outlet capacity, and (3) available reservoir storage. Downstream demand and outlet capacity cannot be changed by improved operations. The available reservoir storage can be changed in two ways: (1) improved inflow volume anticipation and (2) allowing a lower minimum desired reservoir storage.

Table 1. Operations Versus Capital Improvements Simulation Results

No.	Simulation Description	Total Spillage, af	Minimum Reservoir Storage
--	Actual Historical	3,076	0
Historical Inflows			
1	Baseline Historical	1,750	52
2	Improved Operations (98% exceedance level)	1,390	37
3	Increased Reservoir Storage (+465 acre-feet)	0	52
4	**Increased Outlet Capacity (+ 10 cfs at Willey)**	1,659	52
Historical Inflows+20%			
5	Baseline	7,263	52
6	Improved Operations (98% exceedance level)	6,404	34
7	**Increased Reservoir Storage (+2645 acre-feet)**	0	52
8	Increased Outlet Capacity (+ 20 cfs at Willey)	6,204	52

Simulations were performed using historical inflow to develop improved operations planning criteria minimizing spillage without compromising operational flexibility. In the simulations, operational flexibility is allowed by limiting the maximum planned release to a value less than the outlet capacity.

The baseline simulations described earlier assumed zero inflow. Earlier work had indicated the difficulty of predicting inflows. Thus, two seasonal exceedance curves were developed for anticipating inflows. Using the 98% exceedance level for anticipating inflows was found to significantly reduce spillage with minimum risk of falling below a desired reservoir level.

Initially, an operations simulation with inflows anticipated following the 98% exceedance level according to high and low inflow periods was developed. Next, the lowest exceedance level that could be used for each inflow period without reducing the minimum storage was determined by trial and error. This reduced the total spillage 19% from 1,390 to 1,128 acre-feet (simulation 10, Table 2).

As noted earlier, operators prefer to operate the pumps at less than capacity increasing operational flexibility. The historical analysis suggested that this may be possible without increasing spillage during the low inflow season. This was simulated for the entire year, roughly doubling of spillage (simulation 11).

Limiting releases to less than maximum release capacity during the low inflow season reduced spillage slightly (simulation 12). This is because the reduced Willey reservoir release rate allows more demand to be met by other system reservoirs resulting in a decrease in spillage. This indicates that changing the priorities between the reservoirs may at times reduce spillage. Lowering the minimum desired reservoir storage volume (simulation 13) decreased total spillage by 34% from 1,128 to 739 acre-feet.

Table 2. Improved Operations Simulation Results

No.	Simulation Description	Total Spillage, af	Minimum Reservoir Storage
Historical Inflows			
2	Improved Operations	1,390	37
9	Seasonal Inflow Anticipation	1,362	40
10	Maximum Seasonal Inflow Anticipation	1,128	40
11	Entire Year Flexible Operations	2,422	40
12	Low Inflow Season Flexible Operations	1,044	40
13	Low Inflow Season Flexible Operations with Lower Minimum Storage	739	31

RECOMMENDED DAILY OPERATIONS CRITERIA

The recommended daily operations planning criteria result from simulation number 12 which resulted in 1,044 acre-feet of spillage over the 46-month simulation period. However, during a workshop at IID, the operators expressed concern that the minimum storage of 50 acre-feet used in this simulation was too low. Although this value will be reviewed during the next phase, the recommended minimum allowable storage has been increased to 70 acre-feet. This increased the spillage to about 1,400 acre-feet.

Operations criteria are based on three decision parameters that depend on the operational period and reservoir (Table 3). Three operational periods are defined based on historical inflows and demand: (1) critical (high inflows and low demand), (2) critical (low inflows and low demand) and (3) less-critical (low inflow and high demand).

In the *Critical--High Flow* operational period (September-December), the maximum desired release at Willey is the physical capacity and the anticipated inflow is higher. In spite of these measures, spillage may occur when inflows exceed the release capacity or when demand is low.

In the *Critical--Low Flow* operational period (January-February), the maximum desired release at Willey is the physical capacity; however, the anticipated inflow is lower. During this period, limited spillage may occur when demand is low.

In the *Less-critical--Low Flow* operational period (March-August), the Vail system demand is high and the inflow to the reservoirs is lower than the other periods. During this period, a lower maximum desired release is used to allow operational flexibility, and the anticipated inflow is lower. Spillage during this period only occurs due to unexpected rainfall events and maintenance problems.

Table 3. Decision Parameters for Recommended Daily Operations Criteria

		Operational Period		
Reservoir	Decision Parameter*	Critical (Sep – Dec)	Critical (Jan – Feb)	Less-critical (Mar – Aug)
Willey	MDR, cfs	50	50	40
	MAS, af	70	70	70
	Anticipated Inflow, cfs	37	10	10
Russell	MDR, cfs	35	35	35
	MAS, af	70	70	70
	Anticipated Inflow, cfs	2	1	1
Young	MDR, cfs	100	100	100
	MAS, af	70	70	70
	Anticipated Inflow, cfs	23	10	10

*MDR=Maximum Desired Release, MAS=Minimum Allowable Storage

Three possible improvements that may further decrease spillage are:

1. Developing an operational indicator to define operational periods,
2. Establishing a "super-critical" mode when spillage is occurring or imminent, during which actual pump discharge would be maintained at maximum output through hourly adjustments, and
3. Developing an integrated reservoir operations strategy to switch priority between reservoirs when appropriate.

CONCLUSIONS

This study reviewed the historical operations of the three interceptor reservoirs associated with the Vail System to determine the causes of, and to evaluate options for reducing reservoir spillage. Historical analysis indicated the basic cause of reservoir spillage was the combination of relatively high inflows coupled with relatively low irrigation demands. Assuming historical intercepted flows do not increase, relatively inexpensive operational improvements were found to be preferable to costly capital improvements for reducing spillage. A daily, mass-balance model was developed and used to develop improved operational rules. These improved rules are being codified in a DSS for the three operationally linked interceptor reservoirs.