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OPTIMIZING HOURLY HYDRO OPERATIONS AT THE SALT LAKE CITY AREA INTEGRATED PROJECTS

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ABSTRACT

The Salt Lake City Area (SLCA) office of the Western Area Power Administration (Western) is responsible for marketing the capacity and energy generated by the Colorado Storage, Collbran, and Rio Grande hydropower projects. These federal resources are collectively called the Salt Lake City Area Integrated Projects (SLCA/IP). In recent years, stringent operational limitations have been placed on several of these hydropower plants including the Glen Canyon Dam, which accounts for approximately 80% of the SLCA/IP resources. Operational limitations on SLCA/IP hydropower plants continue to evolve as a result of decisions currently being made in the Glen Canyon Dam Environmental Impact Statement (EIS) and the Power Marketing EIS.

To analyze a broad range of issues associated with many possible future operational restrictions, Argonne National Laboratory (ANL), with technical assistance from Western has developed the Hydro LP (Linear Program) Model. This model simulates hourly operations at SLCA/IP hydropower plants for weekly periods with the objective of maximizing Western's net revenues. The model considers hydropower operations for the purpose of serving SLCA firm loads, loads for special projects, Inland Power Pool (IPP) spinning reserve requirements, and Western's purchasing programs. The model estimates hourly SLCA/IP generation and spot market activities.

For this paper, hourly SLCA/IP hydropower plant generation is simulated under three operational scenarios and three hydropower conditions. For each scenario an estimate of Western's net revenue is computed.

1 INTRODUCTION

1.1 Background

Western is a power marketing organization within the Department of Energy (DOE) and is primarily responsible for marketing long-term firm (LTF) capacity and energy from SLCA/IP hydropower resources. Marketing criteria instituted by SLCA also provide customers with other services including short-term firm (STF) capacity and energy, firm and nonfirm transmission, maintenance or breakdown, economy energy and fuel replacement, interchange, area load control, and emergency assistance.

Since Western is a purely hydropower based system, its generation capability inherently has a high degree of variability. In recent years, annual electricity generation from SLCA/IP dams has varied by more than a factor of two, ranging from over 11,000 GWh in water year 1984 to less than 4,800 GWh in 1990. The wide range of SLCA/IP electricity generation levels that occurred over the seven year period is an indication of the large degree of uncertainty in the SLCA/IP resource. In addition to hydropower variability, Western must be prepared to respond to several other uncertainties including unscheduled outages, downed transmission lines, and erratic acts of nature. Another uncertainty, operational constraints, will be decided by the Glen Canyon Dam Environmental Impact Statement (EIS) and other environmental regulations that may be issued in the near future. In general, restrictions reduce operational capacity and redistribute water releases from high load months to months with lower loads. Reductions at Glen Canyon Dam and other integrated

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project resources will result in significant adverse repercussions in the SLCA that will reverberate throughout Western. The SLCA must reshape its office in order to meet a wider range of energy and environmental objectives. The role that Western will play in regional power markets is being examined under studies conducted in support of the SLCA Power Marketing EIS and a Congressionally mandated power replacement methods report.

Decisions made by Western staff over the next couple of years will have financial and operational impacts that will last for decades. Western and ANL have developed a number of simulation tools to analyze various potential outcomes in support of Western's decision making process. One of these tools, the Hydro LP [linear program] model was used to analyze SLCA/IP resource operations under numerous hydropower operational restrictions and different power marketing criteria.

1.2 Historical SLCA/IP Hydropower Operations

Within the limits imposed on its operations, the SLCA/IP are, in general, operated to maximize the value of the resources to the regional power market. Western dispatchers use spot market prices as a barometer that measures the hourly value of hydropower energy. Although the first priority of a dispatcher is to meet Western's LTF obligations, hourly SLCA/IP operations do not normally follow firm loads. When hydropower resources can be operated with a high degree of flexibility (see Table 1), SLCA dispatchers purchase energy during off-peak hours at relatively low prices and sell energy on the spot market during on-peak hours at higher prices. However, as a result of environmental concerns, operational constraints were placed on Glen Canyon Dam in 19xx. The operational constraints, known as interim flow restrictions (see Table 1), will be imposed until the Glen Canyon Dam EIS restrictions become effective. Since Glen Canyon Dam accounts for approximately 80% of SLCA/IP capacity and energy, interim restrictions have resulted in the selling of hydropower energy during off-peak hours and the purchase of energy during on-peak hours.

Hydropower conditions also affect the operations of SLCA/IP facilities. During above normal hydropower conditions, energy in excess of LTF commitments is sold on the spot market or as STF energy. Energy purchases must be made under low hydropower conditions.

2 HYDRO LP MODEL METHODOLOGY

The objective of the Hydro LP model is to determine hourly SLCA/IP operations that minimize net operating costs. SLCA net costs are comprised of spot market purchases, supply source energy costs, and revenues from spot market sales. The model considers hydropower dam operations for the purpose of serving SLCA firm loads (both LTF and STF) and project use loads.

The Hydro LP model estimates Western's participation in the spot market to purchase energy to serve its loads and to sell energy to increase its revenues. These activities are based on spot market prices as determined by other simulation models or as estimated through an analysis of historical information and observations. Spot market purchases and sales depend on the amount of water available for hydropower generation, on Western's hourly firm commitments, and on flow restrictions at each of the SLCA/IP dams.

Operational restrictions incorporated into the Hydro LP model include (1) minimum and maximum flow restrictions, (2) hourly and daily ramp rate restrictions, and (3) minimum and maximum elevation levels at the Crystal Reservoir. The Hydro LP model also includes a minimum transaction margin that is required for off- to on-peak hydropower shifting and accounts for area load control services and IPP spinning reserve requirements.

Maximum output levels are based on maximum flow restrictions and representative water-to-power conversion factors. The maximum output is also adjusted for IPP spinning reserves and area load control services. Minimum output levels are based on minimum flow restrictions and representative water-to-power conversion factors. The minimum output is also adjusted for area load control services.

The Hydro LP model assumes that the hourly operation of Morrow Point depends on water releases from Crystal and on side flows between these two dams. Both Crystal and Morrow Point are on the Gunnison River and are part of the Colorado River Storage Project. The reservoir elevation at Crystal must be within the narrow range dictated by the Bureau of Reclamation (BOR). Because of the close proximity of Morrow Point to Crystal and the characteristics of the Gunnison River channel between the two dams, hourly releases at Morrow Point must be closely monitored to ensure that reservoir elevation constraints at Crystal are not violated. The Hydro LP model uses an area/capacity table for the Crystal Reservoir to estimate the change in elevation level per acre-foot of in-flow and out-flow. In-flows to Crystal include water releases from Morrow Point and side flows.

Table 1 Operational Restrictions at Glen Canyon Dam

	Operational Restrictions		
	High Flexibility	Interim Flows	Low Flex.
Min. Release Rate (cfs)	1,000[a] or 3,000[c]	8,000 or 5,000[d]	Steady flow
Max. Release Rate (cfs)	31,500	20,000[e]	Steady flow
Max. Daily Fluctuation (cfs/day)	NR[b]	5,000, 6,000, or 8,000[f]	Steady flow
Up-Ramp Rate (cfs/h)	NR	2,500	0
Down-Ramp Rate (cfs/h)	NR	1,500	0

[a] Labor Day to Easter.
[b] NR denotes no restriction.
[c] Easter to Labor Day.
[d] 8,000 (7 a.m.-7 p.m.); 5,000 (all other hours).
[e] During wet years, the maximum flow rate may be exceeded; however, flows during this time must be steady.
[f] Limited to 5,000 cfs/day for months with water releases of less than 6 million acre-feet; 6,000 cfs/day for months with water releases of 6 to 8 million acre-feet; and 8,000 cfs/day for months with water releases greater than 8 million acre-feet.

The Hydro LP model runs on a weekly basis to estimate hydropower operations and spot market activities for each hour in the week. Because of ramp rate restrictions and monthly BOR mandated water releases, each hour of operation in the simulated week depends on all other hours in the simulation period. For this analysis, each week simulated begins at midnight on a Thursday and ends at midnight on the following Wednesday. These beginning and ending times were chosen to minimize simulation boundary problems (i.e., beginning and end effects) associated with the interaction of weekend firm loads with spot market prices and ramp rate restrictions (both hourly and daily).

3 HYDRO LP MODEL SIMULATIONS

Figure 1 shows hourly simulated SLCA/IP operations and spot market activities for a typical summer day. With high operational flexibility, SLCA/IP hourly generation is low during off-peak periods, ramps up rapidly in the morning, and ramps down at night. Minimum generation levels are constrained by minimum flow restrictions at each of the SLCA/IP dams and by approximately 50 MW for area load control regulations. During off-peak hours the model predicts that generation is less than firm loads and Western makes spot market purchases to fulfill its firm obligations.

Maximum generation levels are constrained by physical operational limitations at each dam, area load control area regulations, and approximately 56 MW for IPP spinning reserve obligations. Note that during some on-peak hours, the model projects that Western maximizes the value of its resources by generating electricity above firm loads. This energy is sold to the spot market when on-peak prices are the highest.

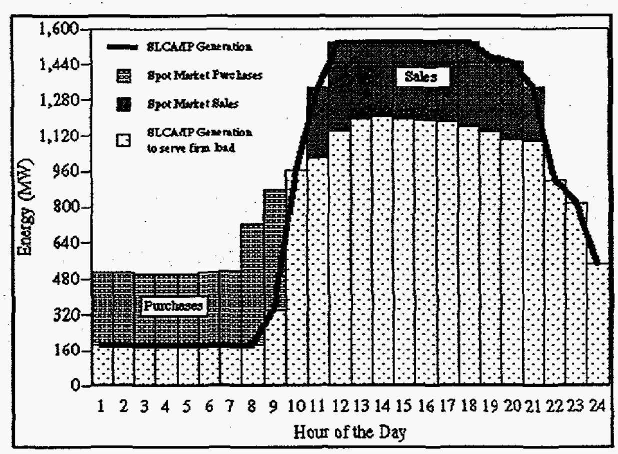

Figure 1. Simulated SLCA/IP Generation Under High Operational Flexibility

Under interim flow restrictions, operational flexibility decreases and spot market purchases are projected by the model to shift from off- to on-peak hours (see Figure 2). This is in direct contrast to the high-flexibility scenario in which all purchases are projected to be made during night and early morning and sales are made during on-peak hours. In part, these spot market activities occur because of the hourly ramp rate restrictions.

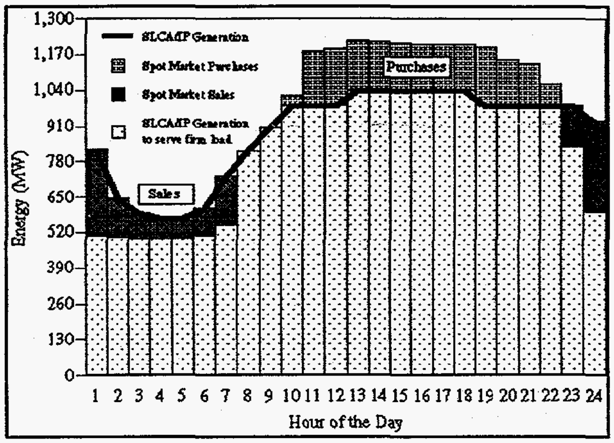

Figure 2. Simulated SLCA/IP Generation Under Interim Flow Operational Restrictions

Note that compared to the high flexibility scenario, hourly changes in SLCA/IP generation are significantly lower. Also, changes in firm loads during the early morning and late evening are greater than the maximum allowable hourly ramp rates (both the up-ramp and the down-ramp). Demands also have a larger range of fluctuation than the maximum allowable daily fluctuation. This maximum daily fluctuation constraint limits Glen Canyon's maximum output at the time of peak demand, thus, reducing the operable capacity of the hydropower resource. Note that if sustained for a longer period of time, hourly ramp rate restrictions would allow a higher level of operational capacity, but would violate the maximum daily fluctuation constraint.

SLCA/IP resources could be operated at a higher generation level during off-peak periods thereby increasing the allowable maximum operational capacity at times of peak demand. However, under the hydropower conditions analyzed in this study there are insufficient water resources (i.e., energy) available to sustain this high level of continuous output. Under more favorable hydropower conditions, the maximum operable capacity is higher but decreases significantly under low hydropower conditions.

A very stringent operational scenario was also simulated by the Hydro LP model. Under the low-flexibility scenario all SLCA/IP hydropower plants are constrained to constant hourly releases; that is, steady flows or water releases during all hours in a month. Maximum hydropower output or operational capacity equals the average SLCA/IP generation (i.e., monthly generation/hours in a month). In addition, this scenario also redistributes energy on a monthly basis such that energy releases are higher during months with relatively low load (e.g., the spring). Energy releases are therefore lower during months of high load (e.g., the Summer). As shown in Fig. 3, relatively large quantities of energy must be purchased to serve LTF hourly loads when spot market prices are high. On the other hand, energy must be sold or water spilled during off-peak hours when prices are relatively low.

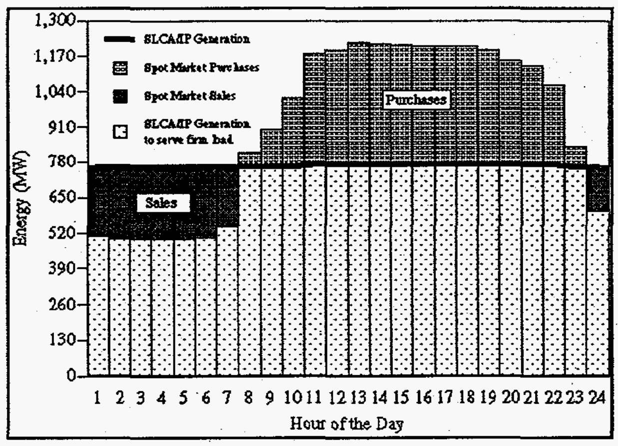

Figure 3. Simulated SLCA/IP Generation Under Low Operational Flexibility

Loss in operational flexibility not only restricts Western's ability to follow firm load; it also significantly reduces SLCA/IP operational capacity. As shown in the SLCA/IP generation exceedance curves in Figure 4, maximum generation levels among operational scenarios range from 1,600 MW under the high-flexibility scenario to approximately 950 MW under the low-flexibility scenario. Variations in the generation level under the low-flexibility scenario are caused by changes in monthly water volume. Except for a transition period between months, generations within a month are constant.

Table 2 summarizes projected spot market activities

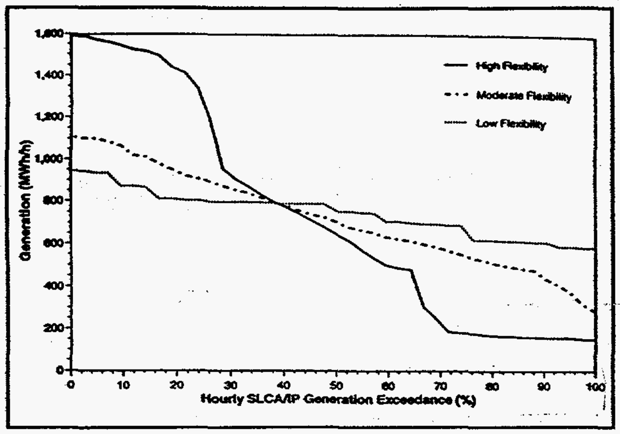

Figure 4. Simulated SLCA/IP Generation Exceedance Curves Under Normal Hydropower Conditions

by operational scenario and hydropower condition. The table shows that spot market on-peak purchases decrease with wetter hydropower conditions. Note that this decrease is much greater for the high flexibility scenario as compared to the low flexibility scenario. The opposite situation is projected for on-peak sales; that is, on-peak sales increase significantly with higher hydropower energy. This increase is substantially greater for the high operational flexibility scenario as compared to the on-peak spot market purchases for the low flexibility scenario. In general, spot market activities are lower for the interim flow scenario as compared to the other two scenarios. This occurs because the interim flow constraints are such that operations of SLCA/IP power plants follow firm load loads more closely.

The energy cost of decreasing operational flexibility is shown on Table 3. Under the high flexibility scenario, the Hydro LP model estimates that spot market purchase costs are approximately $2 million higher than sales revenues. For this analysis, it was assumed that under high hydropower conditions most of the excess energy would be sold under STF contracts. If the excess energy were sold on the spot market instead, estimates of revenues from spot sales would be significantly higher.

When operational restrictions are reduced to interim flow levels, purchase costs are approximately $12 million higher than sales revenues or about $10 million dollars per year more expensive than the high flexibility alternative. When operational flexibility is low net spot market activity costs increase by an additional $5.5 million per year above the interim flow scenario, wherein, purchase costs are $17.5 million more than sales revenues.

The pattern of spot market purchase costs and sales revenues is a function of both the level of spot market transactions shown on Table 2 and the price of electricity. Note that on Table 3, under the high flexibility scenario the purchase price is significantly lower than the sales price. However, under the low flexibility scenario, Western must purchase energy at a high price and sell it on the spot market at a relatively low price.

In addition to increased energy costs, losses in operable capacity must be eventually be replaced. Replacement options are currently being explored by Western and proposed methods for conducting power replacement analyses will be submitted in a report to Congress in the summer of 1996.

4 CONCLUSION

The SLCA must reshape its office in order to meet a wider range of energy and environmental objectives. It must operate its resources taking into account a much wider range of energy and environmental considerations than it had in the past. In order to prepare for future outcomes and to take appropriate action, Western is conducting numerous analyses and developing analytical tools. The Hydro LP model is one tool that is being used to analyze the effects of operational constraints on SLCA/IP operations and the economics of reliably meeting its firm contracts.

In general, restrictions reduce both operational flexibility and capacity. In addition, some restrictions redistribute water releases from high load months to months with lower loads. As estimated by the Hydro LP model, the energy costs of changing operations can increase by over $12 million for the low flexibility scenario. Additional costs for replacing losses in operable capacity will be incurred.

TABLE 2 Projected Annual Spot Market Sales and Purchases by Hydropower Condition and Hydropower Operational Scenario

Hydropower Condition and Period	Hydropower Operational Scenario					
	High Flexibility		Interim Flows		Low Flexibility	
	Purchase (GWh/yr)	Sale (GWh/yr)	Purchase (GWh/yr)	Sale (GWh/yr)	Purchase (GWh/yr)	Sale (GWh/yr)
Dry Conditions						
On- Peak	790	477	992	6	1479	8
Off-Peak	1,126	51	451	44	156	147
Total	1,916	528	1,443	50	1,635	155
Normal Conditions						
On-Peak	439	1009	265	215	721	127
Off-Peak	858	159	105	276	27	677
Total	1,297	1,168	370	491	748	804
Wet Conditions						
On-Peak	92	1412	66	515	193	363
Off-Peak	492	337	8	759	12	993
Total	584	1,749	74	1,274	205	1,356
Weighted average	1,436	1,010	842	394	1,084	605

TABLE 3 Western Energy Transactions by Hydropower Operational Scenario

Spot Market Activity	Hydropower Operational Scenario					
	High Flexibility		Interim Flow		Low Flexibility	
	Average Annual Revenue ($\$10^6$)	Average Price ($/MWh)	Average Annual Revenue ($\$10^6$)	Average Price ($/MWh)	Average Annual Revenue ($\$10^6$)	Average Price ($/MWh)
Sales	28.70	28.4	9.20	23.4	12.72	21.0
Purchases	30.63	21.3	21.08	25.0	30.33	28.0