APPENDIX Q

POWER SYSTEM BENEFITS

Q-1. Introduction. The analysis of benefits for a system of interdependent hydropower projects generally follows the basic procedures outlined in Chapter 9. However, system benefit analysis is more complex than single-project analysis because (a) downstream projects may be dependent upon headwater storage projects for a portion of their power benefits, and (b) a share of those downstream benefits must often be allocated to the headwater project for it to be incrementally justified. The concepts of system benefit analysis can best be illustrated by examining some simple systems. Procedures for allocating benefits between headwater storage projects and downstream projects which benefit from storage regulation are illustrated by a single-reservoir system. Allocation of benefits among multiple storage projects is illustrated by a two-reservoir system.

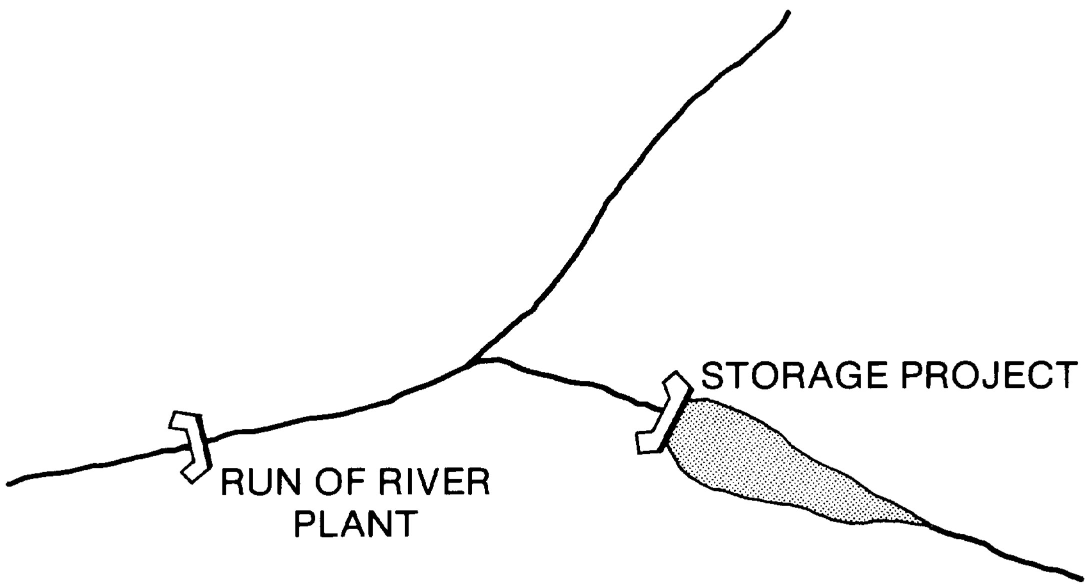
Q-2. Single-Reservoir System.

a. System Description.

(1) The general concept of reservoir power system benefit analysis will be illustrated by examining a simple system consisting of an existing run-of-river plant and a proposed storage project to be located upstream (Figure Q-1). Although in a normal planning study alternative power installations would be tested to simplify the example, it is assumed that installed capacities at both plants will be based upon a 30 percent firm plant factor.

(2) Power studies would be made for two scenarios: (a) with the existing 100 MW run-of-river project only, and (b) with the run-of-river project plus the proposed storage project. The table at the bottom of Figure Q-1 shows the output of the projects under the two scenarios. Note that increasing the firm energy output of the run-of-river project permits expansion of the powerplant by 30 MW. The annual costs associated with the proposed plan are:

Storage Project	
Dam and reservoir costs	$10,000,000
At-site power costs	7,500,000
Run-of-River Project	
Powerhouse expansion	2,500,000
Total Cost	$20,000,000



	Average Energy (MWh)	Firm Energy (MWh)	Installed Capacity (MW)	Dependable Capacity (MW)
Initial Installation				
Run-of-river plant	420,000	263,000	100	65
Proposed Plan				
Run-of-river plant	440,000	342,000	130	110
Storage project	217,000	197,000	75	70

NOTE: The average annual and firm energy values were obtained from sequential routing studies (Sections 5-8 through -14). The installed capacities are based upon a firm plant factor of 30 percent, and the dependable capacity values are based upon the average capacity available in the peak demand months (Section 6-7g).

Figure Q-1. System with one storage project and one run-of-river plant

TABLE Q-1
Computation of Benefits for One-Reservoir System

Initial Installation

Capacity benefit = (65,000 kW) x ($196.40/kW-yr) =	$12,800,000
Energy benefit = (420,000,000 kWh) x (17.1 mills/kWh) =	7,200,000
Total benefit =	$20,000,000

Run-of-River Plant

Capacity benefit = (110,000 kW) x ($196.40/kW-yr) =	$21,600,000
Energy benefit = (440,000,000 kWh) x (17.1 mills/kWh) =	7,500,000
Total benefit =	$29,100,000

Incremental gain in benefits at run-of-river plant =
$29,100,000 - $20,000,000 = $9,100,000

Storage Project

Capacity benefit = (70,000 kW) x ($196.40/kW-yr) =	$13,700,000
Energy benefit = (217,000,000 kWh) x (17.1 mills/kWh) =	3,700,000
Total benefit =	$17,400,000

Total benefits of plan = $9,100,000 + $17,400,000 = $26,500,000

b. At-Site Benefits. Table Q-1 shows the computation of benefits for each power installation using power values for the coal-fired alternative from Tables 9-3 and 9-5. The net benefits of the total plan are ($26,500,000 - $20,000,000) = $6,500,000; so the overall plan appears to be justified. However, in accordance with Section 1.6.2(b) of Principles and Guidelines, each separable component of the plan must also be incrementally justifiable. The two power installations are separable, and the incremental net benefits of each can be computed as follows:

Powerhouse expansion at run-of-river project:

Net Benefit = (incremental benefits at run-of-river plant) - (cost of run-of-river plant expansion)
= \$9,100,000 - \$2,500,000 = \$6,600,000

At-site power at storage project:

Net Benefit = (at-site power benefits) - (at-site power costs)
= \$17,400,000 - \$7,500,000 = \$9,900,000

c. Cost Allocation.

(1) It can be seen that each separable component can be individually justified. However, the dam and reservoir costs associated with the storage project must also be covered. If the storage project did not exist, neither the at-site benefits at the storage project nor the incremental benefits at the existing run-of-river project would have been realized. Therefore, the dam and reservoir costs must be allocated to the two power installations.

(2) In accordance with accepted practice, the separable cost-remaining benefits (SCRB) allocation method would be used for making this allocation. In this case, the remaining benefits from the two separable components are the same as the respective net benefit values computed above. The total remaining benefits would then be \$6,600,000 + \$9,900,000, or \$16,500,000. The joint costs to be allocated are the dam and reservoir costs for the storage project, which equal \$10,000,000 (see Section Q-2a(2)).

(3) The joint costs would be allocated as follows:

Powerhouse expansion at run-of-river project:

Allocated joint cost

$$= (\text{total joint cost}) \frac{(\text{net benefit at run-of-river plant})}{(\text{total remaining benefits})}$$

$$= (\$10,000,000) \frac{(\$6,600,000)}{(\$16,500,000)} = \$4,000,000$$

At-site power at storage project:

Allocated joint cost

$$= (\text{total joint cost}) \frac{(\text{net benefits of storage project})}{(\text{total remaining benefits})}$$

$$= (\$10{,}000{,}000) \frac{(\$9{,}900{,}000)}{(\$16{,}500{,}000)} = \$6{,}000{,}000$$

d. Benefit Allocation.

(1) The above analysis satisfies cost allocation requirements. However, it is sometimes necessary to do a benefit allocation as well. For example, an overall benefit-to-cost ratio for the storage project may be required for display purposes. This can be done in several ways, but all methods begin by allocating sufficient benefits to cover the cost of each component. That is, \$17,500,000 in benefits would be allocated to the storage project to cover the cost of the dam and reservoir (\$10,000,000) and the cost of at-site power (\$7,500,000), and \$2,500,000 in benefits would be allocated to the powerhouse expansion at the run-of-river project. The "surplus" benefits available for allocation would be computed as follows:

$$\begin{aligned} \text{Surplus benefits} &= (\text{total benefits}) - (\text{benefits already allocated}) \\ &= (\$26{,}500{,}000) - (\$17{,}500{,}000 + \$2{,}500{,}000) \\ &= \$6{,}500{,}000 \end{aligned}$$

(2) Historically, the surplus benefits have been allocated between projects in several ways:

- using the same ratio as used in allocating joint costs
- maintaining the same benefit-to-cost ratio for each component
- dividing the surplus benefits equally between the projects.

The first method is generally preferred. Using that approach, the benefits to be allocated to the run-of-river project would be computed as follows:

$$\text{Allocated benefits} = (\text{surplus benefits}) \frac{(\text{allocated joint costs})}{(\text{total joint costs})}$$

$$= (\$6{,}500{,}000) \frac{(\$4{,}000{,}000)}{(\$10{,}000{,}000)} = \$2{,}600{,}000.$$

The benefits allocated to the storage project would be:

$$\text{Allocated benefits} = (\$6{,}500{,}000)\,\frac{(\$6{,}000{,}000)}{(\$10{,}000{,}000)} = \$3{,}900{,}000.$$

e. Project Benefit-Cost Ratios. The resulting project benefit-cost ratio will be ($2,500,000 + $2,600,000) to ($2,500,000), or 2.0 to 1 for the expansion of the run-of-river plant, and ($17,500,000 + $3,900,000) to ($17,500,000), or 1.2 to 1 for the storage project.

Q-3. Multiple Storage Projects.

a. General. Two situations can arise which would involve the evaluation of multiple-reservoir systems. The first would be the evaluation of a new multiple-reservoir system, and the other would be the addition of a storage project to a system with one or more existing storage projects.

b. System Description. In order to illustrate the allocation of benefits for a new multiple-purpose reservoir system, the system shown on Figure Q-2 will be examined. This system consists of two proposed new headwater storage projects and a single existing run-of-river plant. The annual costs of the elements of the proposed plan are as follows:

Reservoir A	
Dam and reservoir costs	$10,000,000
At-site power	7,500,000
Reservoir B	
Dam and reservoir costs	$ 6,000,000
At-site power	5,000,000
Run-of-river project	
At-site power	$ 2,600,000
Total annual costs	$31,100,000

c. At-Site Benefits.

(1) In the case of a new multiple-reservoir system, benefits occuring at downstream projects would be allocated to the upstream projects in proportion to their "last added" contribution. For the two-reservoir example (Figure Q-2), power studies would be made for four cases:

- with no storage projects (initial installation)
- with both storage projects (proposed plan)
- with only Reservoir A
- with only Reservoir B.

Figure Q-2 shows the power output for each case, and Table Q-2 shows the computation of at-site benefits. Note that the existing run-of-river plant and Reservoir A are identical to the existing run-of-river plant and storage project in the example shown in Section Q-2.

(2) The last added benefits at the run-of-river plant attributable to Reservoir A are computed by subtracting the total at-site benefits for the system without Reservoir A (i.e., the system with Reservoir B only) from the benefits for the system with both storage projects. These last-added benefits would be ($30,200,000 - $27,000,000) = $3,200,000. The last-added benefits attributable to Reservoir B would be ($30,200,000 - $29,100,000) = $1,100,000. Thus, the total incremental benefits at the run-of-river project resulting from the plan ($10,200,000) would be allocated to the storage project in the following proportions: $3,200,000 /($3,200,000 + $1,100,000) = 74% to Reservoir A and the remaining 26% to Reservoir B.

d. Cost Allocation.

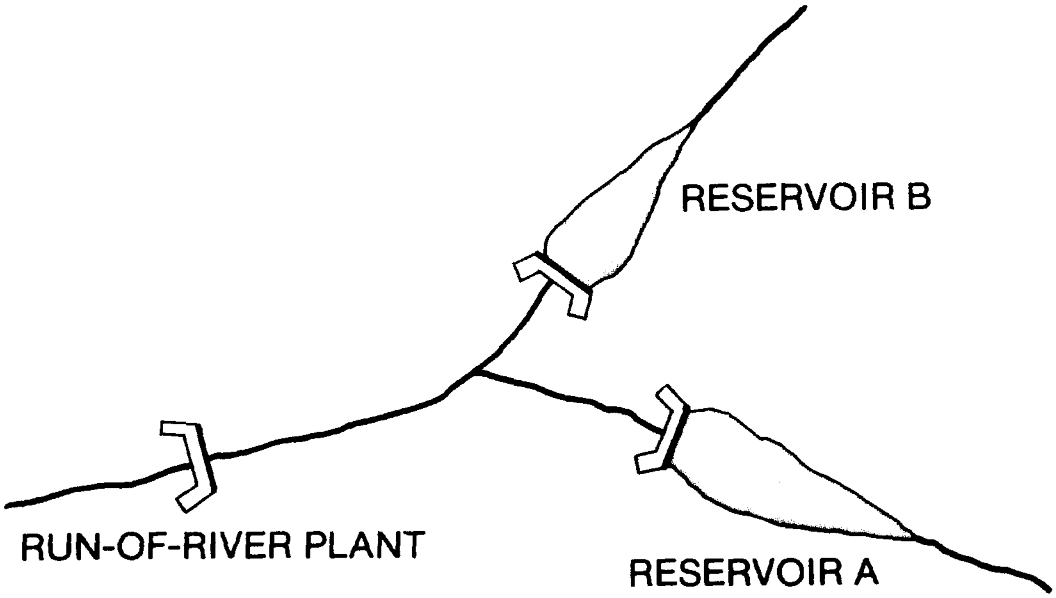
(1) Joint costs of Reservoirs A and B would be allocated as described in Section Q-2b. The first step is to compute the remaining benefits.

Remaining benefits	= (at-site benefits) - (at-site costs)	
Remaining benefits/Reservoir A	= $17,400,000 - 7,500,000	= $ 9,900,000
Remaining benefits/Reservoir B	= $11,300,000 - 5,000,000	= $ 6,300,000
Remaining benefits/R-of-R plant	= $10,200,000 - 2,600,000	= $ 7,600,000
Total remaining benefits		= $23,800,000

(2) The remaining benefits at the run-of-river plant would be allocated to the reservoirs according to the proportions computed in the 'last-added' analysis (Section Q-3c(2)). Remaining benefits would be allocated as follows:

(74%) x ($7,600,000) = $5,600,000 to Reservoir A and
(26%) x ($7,600,000) = $2,000,000 to Reservoir B.

Thus, the total remaining benefits to be allocated to Reservoir A would be the sum of the remaining benefits for Reservoir A and the remaining benefits for run-of-river plant allocated to Reservoir A, or = ($9,900,000 + $5,600,000) = $15,500,000. For Reservoir B, the



	Average Energy (MWh)	Firm Energy (MWh)	Installed Capacity (MW)	Dependable Capacity (MW)
Initial Installation				
Run-of-river plant	420,000	263,000	100	65
Proposed Plan				
Run-of-river plant	445,000	354,000	135	115
Reservoir A	217,000	197,000	75	70
Reservoir B	145,000	131,000	50	45
System With Reservoir A				
Run-of-river plant	440,000	342,000	130	110
Reservoir A	217,000	197,000	75	70
System with Reservoir B				
Run-of-river plant	435,000	318,000	121	100
Reservoir B	145,000	131,000	50	45

Figure Q-2. System with two storage projects and one run-of-river plant

TABLE Q-2. Computation of Benefits for Two-Reservoir System

<u>Initial Installation</u>	
Run-of-river plant	
Total benefit (same as shown on Table Q-1)	= $20,000,000
<u>Proposed Plan</u>	
Run-of-river plant:	
Capacity benefit = (115,000 kW)($196.40/kW-yr)	= $22,600,000
Energy benefit = (445,000,000 kWh)(17.1 mills/kW-yr)	= 7,600,000
Total benefit	$30,200,000
Incremental benefit = ($30,200,000 - $20,000,000)	= $10,200,000
Reservoir A:	
Total benefit = (same as shown on Table Q-1)	= $17,400,000
Reservoir B:	
Capacity benefit = (45,000 kW)($196.40/kW-yr)	= $8,800,000
Energy benefit = (145,000,000)(17.1 mills/kWh)	= 2,500,000
Total benefit	$11,300,000
Total plan: Incremental benefits	
$10,200,000 + $17,400,000 + $11,300,000	= $38,900,000
<u>System with Reservoir A</u>	
Total Plan:	
Incremental benefits (same as shown on Table Q-1)	= $26,500,000
<u>System with Reservoir B</u>	
Run-of-river plant:	
Capacity benefit = (100,000 kW)($196.40/kW-yr)	= $19,600,000
Energy benefit = (435,000,000)(17.1 mills/kWh)	= 7,400,000
Total Benefit	$27,000,000
Incremental benefit = $27,000,000 - $20,000,000	= $7,000,000
Reservoir B:	
Total benefit (same as shown for proposed plan)	= $11,300,000
Total Plan:	
Incremental benefit = $11,300,000 + $7,000,000	= $18,300,000

allocation would be ($6,300,000 + $2,000,000) = $8,300,000.

(3) The allocation of the joint costs of the reservoirs would be computed as follows. The Reservoir A joint costs allocated to powerhouse expansion of the run-of-river plant would be the product of the Reservoir A joint costs ($10,000,000) and the ratio of the remaining benefits at the run-of-river plant allocated to Reservoir A ($5,600,000) to the total remaining benefits allocated to Reservoir A ($15,500,000), or:

For the powerhouse expansion at the run-of-river plant:

$$\text{Allocated joint cost} = (\$10,000,000)\,\frac{(\$5,600,000)}{(\$15,500,000)} = \$3,600,000$$

The Reservoir A joint costs allocated to at-site power at Reservoir A would be the product of the Reservoir A joint costs ($10,000,000) and the ratio of the remaining benefits at Reservoir A ($9,900,000) to the total remaining benefits allocated to Reservoir A ($15,500,000), or

For at-site power at Reservoir A:

$$\text{Allocated joint cost} = (\$10,000,000)\,\frac{(\$9,900,000)}{(\$15,500,000)} = \$6,400,000$$

(4) The allocation for Reservoir B would be computed in a similar manner.

Powerhouse exoansion at run-of-river olant:

$$\text{Allocated joint cost} = (\$6,000,000)\,\frac{(\$2,000,000)}{(\$8,300,000)} = \$1,400,000$$

At-site oower at Reservoir B:

$$\text{Allocated joint cost} = (\$6,000,000)\,\frac{(\$6,300,000)}{(\$8,300,000)} = \$4,600,000$$

(5) The total amount of joint costs allocated to the run-of-river project would be

($3,600,000 + $1,900,000) = ($4,500,000).

e. Benefit Allocation.

(1) Using the same procedure for allocating "surplus benefits" as was used in Section Q-2d, the net benefits for the individual elements of the plan would be computed as follows. The first step is to allocate sufficient benefits to cover the costs of all components of the plan. Subtracting the total cost of the plan (Section Q-3b) from the incremental benefits of the plan (Table Q-2), the surplus benefits are computed as follows:

Surplus benefits = (\$38,900,000 - \$31,100,000) = \$7,800,000.

(2) The surplus benefits would be allocated among the components of the plan in accordance with their allocated joint costs (Section Q-3d).

Surplus benefits, Reservoir A

$$= (\text{total surplus benefits}) \frac{(\text{allocated joint costs, Reservoir A})}{(\text{total joint costs})}$$

$$= (\$7{,}800{,}000) \frac{(\$6{,}400{,}000)}{(\$10{,}000{,}000 + \$6{,}000{,}000)} = \$3{,}100{,}000$$

$$\text{Surplus benefits, Reservoir B} = (\$7{,}800{,}000) \frac{(\$4{,}600{,}000)}{(\$16{,}000{,}000)} = \$2{,}300{,}000$$

Surplus benefits, run-of-river project

$$= (\$7{,}800{,}000) \frac{(\$3{,}600{,}000 + (\$1{,}400{,}000)}{(\$16{,}000{,}000)} = \$2{,}400{,}000$$

(3) The total benefits for each component would be the sum of the benefits allocated to cover the cost of that component (Section Q-3b) plus the allocated surplus benefits.

Total benefits, Reservoir A:
(\$10,000,000 + \$7,500,000) + (\$3,100,000) = \$20,600,000

Total benefits, Reservoir B:
(\$6,000,000 + \$5,000,000) + (\$2,300,000) = \$13,300,000

Total benefits, run-of-river:
(\$2,600,000 + (\$2,400,000) = \$5,000,000

(4) The respective benefit-to-cost ratios would be:

Reservoir A: ($20,600,000) to ($10,000,000 + $7,500,000) = 1.2 to 1
Reservoir B: ($13,300,000) to ($6,000,000 + $5,000,000) = 1.2 to 1
Run-of river: ($5,000,000) to ($2,600,000) = 1.9 to 1.

As noted in Section Q-2d, these allocated system benefits and individual benefit-to-cost ratios are not used in overall plan formulation, but they may be required for budgetary submittals and in the detailed planning of the component projects.

f. Net Benefits.

(1) In formulating the plan for a multiple project system, net benefits must be computed for the total plan, and tests must be made to insure that each separable component of the plan is incrementally justified. For the example system, the separable components are (a) the addition of power at the run-of-river project, (b) the total Reservoir A project, (c) at-site power at Reservoir A, (d) the total Reservoir B project, and (e) at-site power at Reservoir B. Note that the benefits at the individual reservoir projects are based on the last-added analysis: i.e., the sum of the at-site power benefits and the last-added benefits realized at the run-of-river project.

Net benefits/total plan = $38,900,000 - $31,100,000 = $7,800,000

where: $38,900,000 = incremental benefits of total plan (Table Q-2)
$31,100,000 = total costs of plan (Section Q-3b)

Net benefits/expansion of R of R plant
= $10,200,000 - $2,600,000 = $7,600,000

where: $10,200,000 = incremental benefit at R-of-R plant (Table Q-2)
$ 2,600,000 = cost of added power at R-of-R plant (Sec. Q-3b)

Net benefits/total Reservoir A project
= ($17,400,000 + $3,200,000) - $17,500,000 = $3,100,000

where: $17,400,000 = at-site benefits at Reservoir A (Table Q-2)
$ 3,200,000 = last added benefits at R-of-R plant due to Reservoir A (Section Q-3c(2))
$17,500,000 = total cost of Reservoir A (Section Q-3b)

Net benefits/at-site power, Reservoir A
= $17,400,000 - $7,500,000 = $9,900,000

where: $17,400,000 = at-site benefits at Reservoir A (Table Q-2)
$ 7,500,000 = at-site power cost at ?eservoir A (Sec. Q-3b)

Net benefits/total Reservoir B project
= ($11,300,000 + $1,100,000) - $11,000,000 = $1,400,000

where: $11,300,000 = at-site benefits at Reservoir B (Table Q-2)
$ 1,100,000 = last added benefits at run-of-river plant due to Reservoir B (Section Q-3c(2))
$11,000,000 = total cost of Reservoir B (Section Q-3b)

Net benefits/at-site power, Reservoir B
= $11,300,000 - $5,000,000 = $6,300,000

where: $11,300,000 = at-site benefits, Reservoir B (Table Q-2)
$ 5,000,000 = at-site power cost, Reservoir B (Sec. Q-3b)

(2) The total plan and all of its components are feasible. The net benefits of the total plan, at $7,800,000, are larger than the net benefits of the plan with only Reservoir A, which were computed to be $6,600,000 in Section Q-2b.

(3) Note that the Reservoir B project, treated as a whole, is only marginally feasible. If the total plan were feasible, but Reservoir B were not feasible as a separate increment, several courses of action would be available. If it were clearly infeasible, it would be deleted from the plan. On the other hand, if it were only marginally infeasible, Section 1.6.2(b) of Principles and Guidelines possibly could be applied. It states that "Increments that do not provide net NED benefits may be included, except in the NED plan, if they are cost-effective measures for addressing specific concerns." Even though Reservoir B was not in itself justified on a last-added basis, it could possibly be included if it were an element of the plan that produced maximum net benefits.

Q-4. More Complex Systems.

a. The example outlined above represents the simplest case of a multiple-reservoir system. However, the same general principles can be applied to more complex systems. The key to the analysis of complex systems is correctly setting up the with- and without-project power studies.

b. If a storage project is added to an existing reservoir system, it must be analyzed on a last-added basis. Thus, if Reservoir B were added to an existing system which already includes the run-of-river project and Reservoir A, power studies would be made with and without Reservoir B and incremental benefits would be computed. Costs would include the dam and reservoir costs at Reservoir B, the cost of at-site power at Reservoir B (if at-site power is included), and any additional costs required at the run-of-river plant to permit it to develop the additional power resulting from the regulation of Reservoir B. The analysis of the total plan would be similar to the computation of net benefits for the total Reservoir B project, shown in Section Q-3f(1), except that it would be necessary to include any additional costs that might be incurred at the run-of-river plant.

c. The examples described in Section Q-3 assume that the addition of a second reservoir to the system would not change the output of the first storage project. In some cases, addition of a reservoir to an existing system might change the operation of the existing reservoirs, and may even change their energy output and dependable capacity. If this occurs, at least a portion of these increases (or losses) should be credited to the added reservoir. These gains or losses could be identified from the with- and without-project system power studies.