COST/BENEFIT ANALYSIS FOR THE OPERATIONAL APPLICATIONS OF SATELLITE SNOWCOVER OBSERVATIONS (OASSO)

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ABSTRACT

Irrigation and hydropower benefits for the 11 western states by forecast improvement from satellite snowcover area were made based on data supplied by OASSO ASVT's.

INTRODUCTION

It is almost a decade, dating from the early 1970's that satellite technology has been capable of providing relatively high quality images on a frequent enough basis to indicate to hydrologists that a possibility for gathering data on the snowpack area was practical. Both the techniques for mensurating the snowpack area and its application for improving seasonal runoff predictions have been demonstrated (Leaf, 1971; Rango, 1975; Barnes and Bowley, 1974). As a result, an Applications Systems Verification and Transfer (ASVT) program was established, whose major thrust was to extend these efforts to operational forecasting.

The operational employment of satellite snowcovered area measurement (SATSCAM) to runoff forecasting has been evaluated at four ASVT sites strategically located throughout the western United States. To supplement the ASVT technical evaluation, NASA initiated a study to determine the costs and benefits of operationally applying SATSCAM.

Previous benefit estimates due to improved information on the area of the snowpack have used parametric estimates of overall improvement and did not rely upon actual experience or expert evidence on the actual levels of improvement possible. These approaches have not included detailed treatments of the physical mechanisms "driving" the benefits; e.g., increased irrigation value of specific crops, cost differential between hydroenergy and thermal electric energy, etc. The present study was established to use the results and experiences gathered from operationally oriented ASVT personnel whose expertise, knowledge, and estimates form the basis for the benefit estimate presented herein. In this regard, a note of special thanks to all the ASVT personnel for their valuable assistance, consideration, and patience throughout this project.

Benefits Derived from Improved Information

The major benefits of improved snowmelt runoff forecasting are naturally related to the major uses of water.

The major uses of water in the United States, ranked by importance in terms of gross value, are:

- Hydropower
- Irrigation
- Municipal and Industry
- Navigation
- Recreation, Land and Wildlife Management

The principal direct and indirect benefits for each use are given in Table 1.

In addition to the above, the benefits due to flood damage reduction must be added. The direct benefits are the reduction in losses to public and private property and the increases in net income arising from more extensive use of property. The indirect benefits to reduced flood damage result from the reductions of losses caused by the interruption to public and private activities. Major intangible benefits accrue to the prevention of the loss of human life and to positive effects on the general welfare and security of the populace.

Hydroelectric energy production is the largest user of water in the 11 western states and is potentially the largest benefactor of improved streamflow forecasting in terms of energy produced. Approximately 190 terawatt-hours of hydroelectric energy are produced annually in the 11 western states, requiring over 2 billion acre-feet of water. The annual dollar volume of hydroelectric energy sales at current prices is on the order of $6 billion.

Irrigation is second to hydropower in quantity of water used and potential physical benefit from improved knowledge of streamflow. Twenty-five percent ($12 billion) of all crops sold in the United States are produced on irrigated land. Irrigation accounts for approximately 40 percent of all the water withdrawn annually in the United States (with hydropower excluded since it does not withdraw water). Sixty percent of the irrigation water is consumed as evapotranspiration from crops and soil surfaces, making irrigation the largest consumptive user of water. The 11 western states contain approximately 23 million acres of irrigated land and account for approximately 58 percent of the nation's irrigation requirements or approximately 100 million acre-feet of water annually.

The next largest use of water is municipal and industrial water supply. As shown in Table 2 which reports recent annual withdrawals for various uses in the 11 western states, municipal and industrial uses required only 10 percent of the water required by irrigation and less than 1 percent of that required by hydropower. Consequently, the central focus of this study was directed at estimating the benefit of improved streamflow forecasting to hydropower production and to irrigated agriculture.

Estimation of the Upper Bound Value of Water for Hydroelectric

Table 3 summarizes the results of the computation of the value of snowpack runoff water for hydropower production. Baseline data (Colorado State University: Economic Value of Water, 1972) from 1968 shows that the average value of alternative energy was 6.8 mills/kWh at a capacity utilization factor of 48 percent. Data for

Table 1

Generic Benefits of Improved Information for Water Management and Utilization

	HYDROENERGY	IRRIGATION	MUNICIPAL/INDUSTRIAL	NAVIGATION	RECREATION, FISH & WILDLIFE
DIRECT BENEFITS	• Cost savings due to optimal mix of hydroenergy and thermal energy. • Value added by optimal production at upstream/downstream sites • Improved power production scheduling hence improved overall plant efficiency	• Increase in net farm income due to lower production costs • Increase in net farm income due to optimal crop selection • Improvements in operational efficiency of in place irrigation projects.	• Improved surface water withdrawal scheduling hence improved overall waterworks efficiency. • Cost saving by reduction of high cost ground water withdrawal.	• Reduction in cost of transport through improved scheduled releases of reservoirs water storage to improve or expand irrigable waterways. • Increased value of transport services resulting from expanded demand for the improved service.	• Increased revenues from increased utilization of recreational lands and facilities. • Increased populations of higher value fish and wildlife. • Reduction of fish embolism through better control of reservoir releases.
INDIRECT BENEFITS	• Conservation of fossil energy supplies • Conservation of labor	• Increases in net income to Ag. industry suppliers • Reduction in food costs to populace • Reduction in energy required to provide irrigation.	• Reduction of fire insurance rates. • Cost savings to populace due to increased availability of water. • Expansion of industry due to increased availability of water.	• Increased industrial and commercial activity. • Increase utilization/value of land along waterway.	• Increased revenues from the sale of recreational equipment. • Improved health of recreationally active populace.
INTANGIBLE BENEFITS	• Improved level of life due to cheaper energy production	• Improved community facilities and services • Increased level of living.	• Improved standard of living within area.	• Enhanced strategic value of inland waterways.	• Esthetic value of improved waterways and wildlife habitat. • Ecological value of improved waterways and wildlife habitat. • Scientific value of improved water ecosystems.

Table 2

Recent Withdrawals with State and Region[1]
(1,000 Acre/Feet)

STATE	WITHDRAWL YEAR	IRRIGATION	M&I INCLUDING RURAL	MINERALS	THERMAL ELECTRIC	RECREATION FISH & WILDLIFE	OTHER	TOTAL
ARIZONA	1965	7,096	349	102	7	169	78	7,942
CALIFORNIA	1965	29,020	4,131	118	8,220	652	-	38,897
COLORADO	1970	7,826	473	65	19	29	111	9,794
IDAHO	1966	17,668	739	27	-	245	49	25,505
MONTANA	1970	6,292	361	14	67	-	206	8,052
NEVADA	1969	3,301	245	-	63	-	10	4,718
NEW MEXICO	1970	3,206	205	84	66	45	52	3,919
OREGON	1975	7,624	1,581	-	23	36	17	10,878
UTAH	1965	4,803	415	95	7	616	951	7,348
WASHINGTON	1975	6,523	1,934	-	-	-	29	9,886
WYOMING	1968	7,358	134	85	13	-	-	7,977
EVAPORATION		-	-	-	-	-	-	1,862
SUMMARY		100,717	10,567	590	265	1,792	1,503	136,778

[1]Includes both surface and groundwater withdrawls
SOURCE: Westwide State Reports (unpublished)

Table 3

Upper Bound for the Value of Snow for Hydropower

STATE	AVERAGE HYDROPOWER WATER USE (MAF)	AVERAGE HYDROPOWER GENERATION TERA-WATTS-HR.	VALUE OF WATER FOR HYDROPOWER $/AF	VALUE OF WATER FOR HYDROPOWER ($B)	AVERAGE SNOW FRACTION	CONTRIBUTION $B
WASHINGTON	1,204.1	86.6	2.87	3.46	0.67	2.32
OREGON	617.0	30.0	2.87	1.77	0.67	1.18
IDAHO	112.6	8.4	2.87	0.33	0.66	0.22
MONTANA	82.6	7.5	2.87	0.24	0.70	0.17
WYOMING	18.3	1.3	2.18	0.04	0.73	0.03
NEVADA	15.9	2.0	6.85	0.12	0.65	0.07
UTAH	4.1	1.1	2.187	0.01	0.74	0.01
COLORADO	7.6	1.4	2.18	0.01	0.74	0.01
CALIFORNIA	132.3	40.7	6.85	0.90	0.73	0.66
ARIZONA	39.1	7.8	6.85	0.27	0.74	0.20
NEW MEXICO	1.0	0.1	2.18	0.003	0.71	0.002
TOTAL OR (AVERAGE)	2,234.6	186.0	(3.20)	7.15	(0.68)	4.86

1974 (FEA National Energy of Outlook, 1976) summarizing industry averages, shows that this value has risen by a factor of 1.32 to 9 mills/kWh primarily due to increase in the world price of oil. Applying the yearly growth rate of 9.5 percent indicated by the price indices of petroleum, yields a combined factor of 1.60 or a current value of energy of 10.9 mills/kWh at 48 percent capacity utilization. Equivalent adjustment was made for the value of energy at the average capacity utilization factor for each state. Short-run values of water for hydropower were computed using the following equation:

$$V_W = \frac{0.74 \text{ eh y} - 0.08 \left(\frac{\text{eh C}}{\text{f}}\right)}{721.13} \qquad [1]$$

V_W = Value of water used in \$/cfs-yr.

e = Overall plant efficiency

h = Effective head (ft.) (pond elevation minus tailwater elevation)

y = Cost of electricity from cheapest alternative source mills/kWh

C = Annual capital cost of generation/kWh installed \$

f = Annual capacity utilization factor

Data for the quantity of water used for hydropower was determined by trending from current levels, on a state-by-state basis. Average fractions of the total water supply from snowmelt were applied on a state basis to determine the upper bound value of hydropower inputed to snowmelt runoff.

The results shown in Table 3 indicate that the 11 western states use an average of 2,235 AF per year for hydropower. At an average alternate energy cost of \$3.20/AF, the total value of the hydropower generated is \$7.15B. This corresponds to a price of 3.8¢/kWh. Adjusting this value by the average snow fraction of 68 percent yields an upper bound value of \$4.86B for the upper bound contribution of snow runoff to hydropower.

Estimate of the Upper Bound Benefit of Water Used for Irrigation

The value of water used for crop irrigation can be measured by the marginal value inputed to yield increases of existing crops resulting from the use of irrigation water, or from the use of higher value mixes of crops vis-a-vis non-irrigated areas.

The marginal value per acre-foot of water from Ruttan (The Economic Demand for Irrigated Acreage, 1965) amended by communication with Colorado ASVT personnel, and updated to 77 dollars, was computed as the ratio of the total marginal value of irrigated crops (acres x \$/acre divided by total irrigation water used for each state).

Table 4 summarizes the computations for the upper bound value for snowmelt water to irrigation for the 11 western states. The tables indicate that the 11 western states use an average of 112 AF per year for irrigation purposes. At an average net marginal value of \$163/acre, the total value of irrigation is \$3.72 billion. Reducing this value by the fraction of water due to snow and that due to groundwater yields an upper bound value of \$1.74 billion for the contribution of snowmelt water for irrigation purposes.

Table 4

Upper Bound Value of Snowmelt for Irrigation

	ARIZONA	CALIFORNIA	COLORADO	IDAHO	MONTANA	NEVADA	NEW MEXICO	OREGON	UTAH	WASHINGTON	WYOMING	TOTAL AVERAGE
WATER USE FOR IRRIGATION (MAF)	1.05	36.95	14.56	16.79	8.51	3.36	3.13	5.37	4.03	6.27	6.05	112.1
IRRIGATED AREA (M ACRES)	1.178	7.24	2.895	2.761	1.841	0.753	0.823	1.519	1.025	1.224	1.523	22.8
AVERAGE CROP VALUE PER IRRIGATED ACRE ($/ACRE)	820	766	304	248	130	213	389	260	190	516	199	(453)
REVENUE ADJUSTMENT FACTOR (q)	1.09	1.02	.41	.33	.17	.28	.52	.34	.25	.69	.27	(.36)
(268.9 x q) = MARGINAL $/ACRE	294	275	109	89	46	76	139	93	68	185	71	(163)
AVERAGE WATER USE PER ACRE (AF/ACRE)	.89	5.1	5.03	6.08	4.625	4.46	3.60	3.53	3.94	5.1	3.97	(4.9)
MARGINAL $/AF	330	53.9	22.6	14.64	10.64	17.04	36.58	26.34	17.26	26.27	17.88	(33.2)
TOTAL VALUE OF WATER (M$)	346.5	1992.0	329.06	245.8	90.5	57.25	114.5	141.4	69.55	227.4	108.17	3,722.13
SNOW FRACTION	.74	.73	.74	.67	.70	.65	.71	.67	.74	.67	.73	(.71)
% SURFACE WATER USE	30	62	60	84	98	84	.50	84	84	88	96	(65)
(M $) VALUE OF SNOWMELT	76.92	901.58	146.10	138.34	62.08	31.26	40.65	79.58	43.23	134.08	75.81	1,729.63

Note that the upper bound serves here only to show that the value of water for hydropower and irrigation is large and hence an important target for forecast improvement. Estimates for the value of SATSCAM for improving the forecast accuracy were developed by the procedures discussed in the remainder of the paper.

The Economic Impact of Improved Runoff Forecasting

The less perfectly the future supply of water (quantity and timing) is known the less efficient are the water supply management activities. This is illustrated conceptually in Figure 1.

Curve A, the locus of benefits accruing to perfect forecast reflects optimal management of water dependent activities at each level of water supply. For example, the "value" from a perfectly managed volume of water X_o is given by Y_o. Curve B_1, is the locus of the values accruing to water volumes lower than the forecasted quantity X_o. Curve B_2 is the analogous locus to over-forecasts.

To illustrate: if the volume X_o is forecast, and the lesser volume X is obtained, the corresponding value is Y_1. Had X been forecasted correctly the benefit would have been Y'_1. The benefit loss is the difference between the X intercept of curves B_1 and A.

A physical explanation of the benefit loss is that in an attempt to maximize benefits, activities are planned which will utilize the forecasted quantity of water efficiently; if subsequently the supply of water actually obtained differs from that forecasted; efficiency suffers, and the results obtained are less than optimal. This conceptual model was applied to hydroenergy and irrigated uses.

Hydroenergy Benefit Model

To a utility which contracts hydroenergy sales at prime rates, excess water results in benefit losses from sales below prime rates; deficit water results in losses because contracted demand must be satisfied by alternative generation at higher cost.

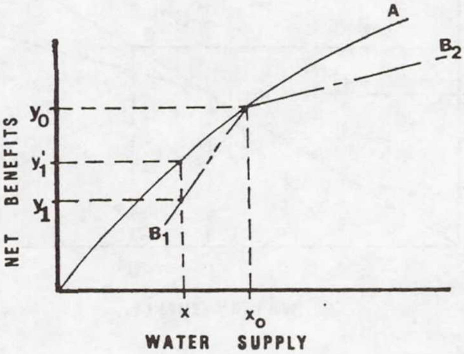


Figure 1. Conceptual Description of Benefits to Improved Forecasting

The curve of maximum potential revenue water supply, shown in Figure 2 as line A, is the locus of sales contracted at prime rates.

$$R = C\,Q_F\,G \qquad [2]$$

where:

R = Value of water at average rate charged for hydroenergy

Q_F = % of mean annual water supply forecasted

G = Average annual generation in kWh per % of mean annual supply

C = Average price charged for hydroenergy, \$/kWh

For a forecasted % of mean flow Q_F, the expected energy is $E_F = Q_F G$: the corresponding expected revenue is $R_F = C\,E_F$.

If the forecast is too low, the available water (Q_1) exceeds that expected by $\Delta Q_1 = Q_1 - Q_F$. The potential revenue at $Q_1 = R_1 > R_F$. However, the "perfect" utility can only sell the excess energy at a rate $C_1 < C$. Thus, the actual revenue will be $R_F + C_1\,\Delta Q_1\,G$, as per curve B_1 in Figure 2. The corresponding benefit loss (L_B) is:

$$L_B = (C - C_1)\,\Delta Q_1\,G \qquad [3]$$

If the forecast is too high, the available water (Q_2) is less than that expected by $\Delta Q_2 = Q_F - Q_2$. Total contracted sales cannot be met by hydroenergy production: the deficit must be supplied by higher cost alternate means of generation. The added cost defines the loss of benefit.

With reference to Figure 2, the potential revenue at Q_2 is R_2. The revenue achieved is computed by subtracting from R_2 the added cost of producing the deficit by alternate means:

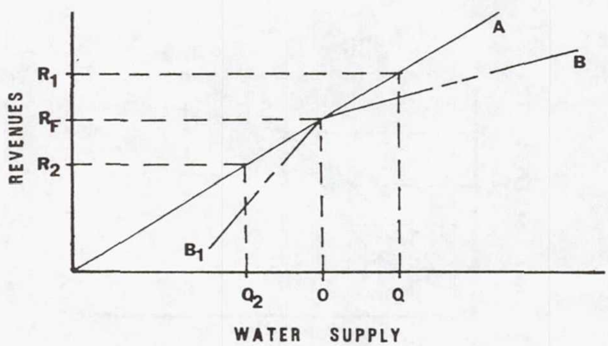


Figure 2. Conceptual Model of Sales Revenues under Stochastic Water Supply Conditions

$$B_2 = C\,Q_F\,G - (C_2 - C)\,\Delta Q_2\,G \qquad [4]$$

where:

B_2 = Hydroenergy revenue obtained when the forecasting supply of water is greater than the realized supply.

C_2 = Price charged for electric energy generated by alternate means.

The annual value of improved forecasting is the difference between the average annual loss of value under current accuracies and the average annual loss of value under the improved accuracies.

From available statistics the value of improved forecasting to hydroenergy marketing is calculated as:

$$V_{IF} = 0.67\,\sigma_{FE}\,G\,C^*\,\beta \qquad [5]$$

where:

V_{IF} = Value of improved forecasting

σ_{FE} = Standard deviation of forecast error

G = Average annual generation

C^* = Mean of the difference in prime and secondary hydropower tariffs and the difference in hydroelectric and steam-electric production costs

β = Fractional improvement in forecast due to SATSCAM

The hydroenergy benefit model derived uses available empirical data consistent with planning and marketing operations currently practiced in the western states.

Irrigation Benefit Model

Existing methods of estimating irrigation benefits employ empirically based linear programming techniques. Such a technique for computing the benefits of improved streamflow forecasting to irrigation is the linear programming method developed by the SCS (Soil Conservation Service: An Evaluation of the Snow Survey and Water Supply Forecasting Program, February 1977), and tested for three key project areas in the western United States: the Salt River Project in Arizona, the Owyhee Project in Oregon-Idaho, and the Clarks Fork area in Montana.

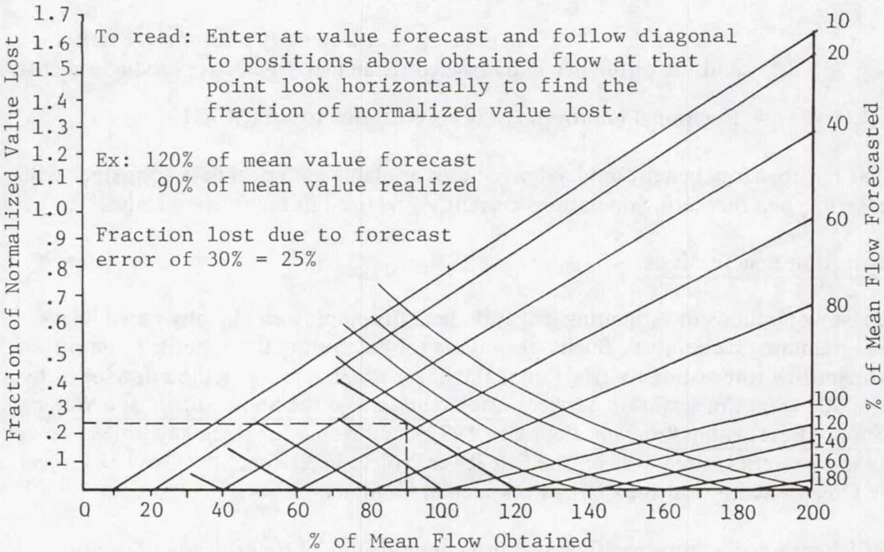
SCS developed a crop-specific linear programming model for each site. Specific inputs included: the water requirements per acre of crop, the levels of irrigation, and existing limitations on regional crop acreages and availability of land. Model outputs are net revenues and optimal acreages for various levels of water availability.

SCS chose eight representative crops for each project area: it used 1973 prices derived from 1976 U.S. Water Resources Council data. The model estimates potential maximum benefits of improved forecast to irrigation.

The SCS model was modified and adapted by ECOsystems to produce a generalized irrigation benefit model which eliminated the need for specific linear programming at each site.

The SCS technique was generalized by normalizing the results of the SCS River Project simulation. The value of forecast improvement is the difference between the benefit loss calculated for the existing and improved forecast performance level. The benefit loss is given in Figure 3 as the difference of value obtained for a perfect forecast and that obtained for the actual quantities of water experienced. This benefit loss determination assumes optimum response by agricultural managers to water supply forecasts.

The total value of the crops produced at mean flow and with perfect forecast was normalized to the total number of irrigated acres for the Salt River Project for the base year 1973 chosen for the SCS simulation. The revenue was normalized by the revenue adjustment q, the ratio of the average revenue per irrigated acre for new sites under study to the revenue of Salt River in 1973 = $7.50/acre.



*Note value lost (expressed as a fraction of the value obtained zero error @ mean flow)

Figure 3. Graph for the Calculation of the Value Lost at the Salt River Project under Stochastic Water Supply Conditions

$$q = \frac{I}{B} \quad [6]$$

where:

I = The average revenue per irrigated acre at new site

B = The average crop revenue per irrigated acre of the Salt River Project in 1973.

The value lost due to any level forecast error is computed from equation [7] using the relationship graphically presented in Figure 3.

$$V_L = \alpha\, q\, A\, k \quad [7]$$

where:

V_L = Value lost due to forecast error

α = Annual fraction of normalized value lost (obtained from Figure 3 for a given forecasted percent of mean flow and realized percent of mean flow)

q = Revenue adjustment factor

A = The irrigated acreage for the geographical and base year

k = Average added value due to irrigation; i.e., for the Salt River Project with a perfect forecast at mean flow as determined by the SCS model = 268.90.

COMPUTERIZATION OF BENEFIT MODELS

Two computer models were developed for computing the benefit of improved forecast accuracy to irrigated agriculture and hydroelectric electric energy. Both models are interactive, requiring input information on the level of forecast improvement, existing forecast accuracy, and streamflow variability. The irrigation model additionally required the input of irrigated acreage and average value of crops per acre for each area. The hydroelectric energy benefit model required the input of average annual generation hydroelectric and steam-electric production expenses, and revenues received from primary and secondary energy sales for each subregion.

The irrigation model employs multiple regression relationships to weight the input parameters. Outputs are current benefits to improved forecasting for the irrigated acreage within each subregion and a single aggregate value of the total benefit for all the subregions considered. The hydroenergy model computes the current values of the benefit to improved forecast on a subregional basis and further summarizes the computations with a total value for all subregions.

Stochastic models were also developed and used to check the results of the models using simulated yearly streamflows.

Data Base Development

Empirical data required for the exercise of the benefit models were obtained from numerous sources. The individual ASVT personnel and local hydrologic experts were of great assistance in the collection of accurate, up-to-date data.

Analysis of the benefit of SATSCAM to irrigation and hydroelectric energy required the development of three extensive data bases: one for the basic characterization of the subregions which are impacted by snow survey forecasting, the second to provide the data inputs for the irrigation simulation model, and the third to provide the data inputs for the hydroenergy simulation model. These data bases contain geographically specific information at as fine a level of granularity as is presently available consistent with the total area covered.

Irrigated acreage data were not available on a project-by-project basis but were collected on a subregion basis. Hydroelectric and steam-electric energy data were available on a project basis.

The Snow Survey Forest Unit of the Soil Conservation Service provided data on average streamflow, streamflow coefficient of variation, forecasts, and forecast accuracy for 361 primary snow survey forecast points covering the 11 western states. Twenty additional forecast points with the supporting data were obtained from the California Department of Water Resources.

Estimates of the irrigated acreage which could potentially benefit from SCAM were computed by adjusting the total irrigated acreage within each subregion by the fraction of surface water to total water used to irrigate those lands. These data were obtained from the USGS 1975 Water Use Survey (The summary form of this data is reported in Estimates of Water Use in the United States in 1975 U.S.G.S. Circular #765). Average annual crop value per acre were extrapolated from 1976 crop value/acre statistics calculated by the Bureau of Reclamation for each of its irrigation projects. These values were used to produce an area-weighted annual crop value/acre for each snow survey impacted subregion.

Electric energy data were acquired for the plants located within the 11 western states as listed by the Federal Energy Regulatory Commission (FERC) and the Energy Information Administration (EIA). These data, reorganized on a subregion basis, included: (1) 1978 average annual hydroelectric energy generation (MWH); (2) current estimates of hydroelectric production expenses (mills/kWh); (3) current estimates of steam-electric production expenses (mills/kWh); and (4) current estimates of the revenues obtained from the sale of prime and secondary energy. Production expenses initially based on 1976 figures, and energy sales revenues, initially based on 1975 figures, were adjusted for inflation.

Benefit Computation Results

The estimated 6% relative forecast improvement from the Colorado ASVT personnel and the extensive data bases previously described were used in the computer benefit models and resulted in a computed total average annual SATSCAM benefit of $38M for the irrigation and hydroenergy for the western United States: $28M/year for irrigation and $10M/year for hydroenergy.

Irrigated agriculture is the primary benefactor of SATSCAM receiving 74% of the benefit of $28M annually. Figure 4 depicts the regional benefits to irrigated agriculture and also shows the average per acre benefit received in these regions.

The Pacific Northwest region receives the largest portion of the agricultural benefit despite receiving the lowest per acre benefit of all the regions. This is a result of the relatively large crop acreage irrigated by the surface water in the Pacific Northwest region as compared to other regions compounded with the relatively lower values of crops planted.

The Lower Colorado region, which is relatively water scarce, receives the largest per acre benefit: $8.95/acre. The Lower Colorado has 1/100 of the acreage irrigated by surface water relative to the Pacific Northwest but generally plants high value irrigated crops.

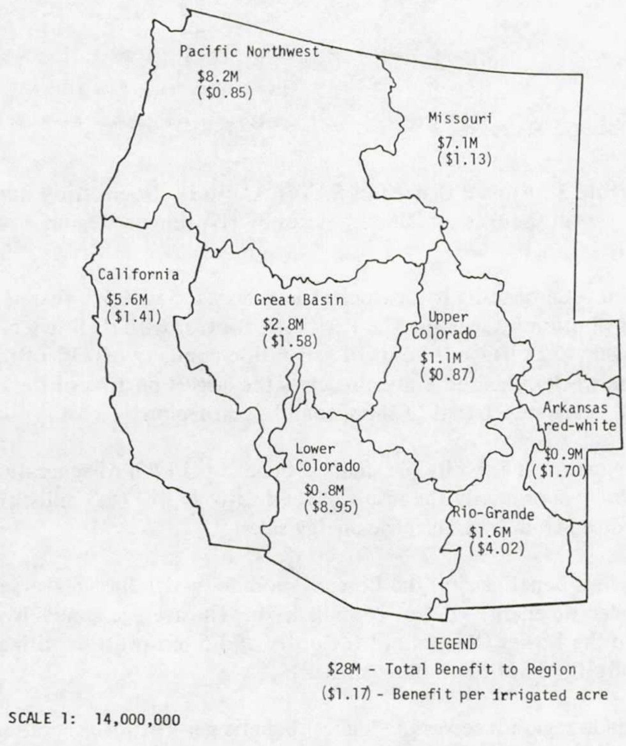


Figure 4. Annual Benefit of SATSCAM to Irrigated Agriculture in the Western United States by Hydrologic Region

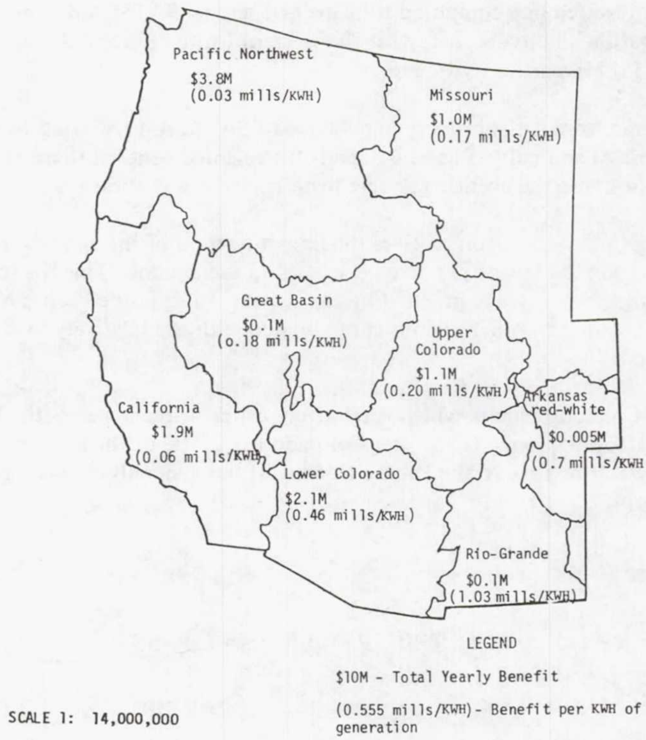


Figure 5. Annual Benefit of SATSCAM to Hydroelectric Energy in the Western United States by Hydrologic Region

The estimated total benefits to hydroelectric energy is $10M per year. Figure 5 depicts the distribution by region. The Pacific Northwest with its heavy concentration of hydropower (132 terrawatt-hours of generation annually or 73% of the total generation in the western United States) receives the largest portion of the benefit (38% of the total), nearly twice that of the second largest region.

The Pacific Northwest exhibits the smallest benefit per kWh of generation, 0.028 mills/kWh which is primarily the result of the relatively low (8.3 mills/kWh) return per kWh received from hydroelectric energy sales.

The next highest beneficiary is the Lower Colorado, which has an average revenue from hydroelectric energy sales of 26 mills/kWh. The average annual hydroelectric generation in the Lower Colorado of the order of 4.5 terrawatt-hr with a computed annual benefit of $2.1M (0.46 mills/kWh).

The Rio Grande region receives the highest benefit per kWh of generation at 1.03 mills/kWh, but exhibits the lowest total benefit of only $0.1M due to the small amount of annual hydroelectric generation on this region (0.096 terrawatt hr).

SATSCAM IMPLEMENTATION COSTS

The cost associated with employing SATSCAM operationally consists of four components: satellite data products, image interpretation, data implementation, and equipment. Costs associated with satellite research and development and with operational SATSCAM "start up" in a forecasting scheme have been considered sunk for purposes of these estimates. An analysis of the cost of each of the non-sunk components was derived from data supplied by the Colorado ASVT site personnel.

The Colorado ASVT effort focused on six study watersheds covering a total area of 9295 km^2. Five Landsat frames were required to provide adequate basin coverage for each data. The forecast period during which SATSCAM was used extended from mid-March to mid-June. Eight observations (image dates) were used during this period. Using a Landsat per frame cost of $10, the total cost of image procurement was $400. Image interpretation for the six basins required 16 man-days per season and resulted in a total cost of $800. Implementing the data into the forecasting scheme required an additional 8 man-day/season of effort at a cost of $600. The total seasonal cost, exclusive of equipment, was 1,800 or $0.194/$km^2$.

The Colorado ASVT used a conventional zoom transfer scope (ZTS) for image analysis. Typical capital cost for the ZTS is $10K. The yearly capital equipment cost was computed assuming a utilization factor of 25% and amortizing the cost over 10 years at $250. The total cost associated with SATSCAM in the Colorado ASVT was $2,050 which equates to 0.22/km^2.

Extrapolating to the 2,238,890 km area impacted by snow-survey forecasting in the western United States, the total yearly cost of employing SATSCAM is approximately $493K.

SUMMARY AND CONCLUSIONS

The results of the OASSO ASVT's have been used to estimate the benefits to the added information available from satellite snowcover area measurement. Estimates of the improvement in runoff prediction due to addition of SATSCAM have been made by the Colorado ASVT personnel. The improvement estimate is 6–10%.

This data was applied to subregions covering the western states snow area amended by information from the ASVT and other watershed experts to exclude areas which are not impacted by snowmelt runoff. Benefit models were developed for irrigation and hydroenergy uses. Results of the benefit estimate for these two major uses yielded a yearly aggregate benefit of $38M.

Cost estimates for the employment of SATSCAM based upon the Colorado ASVT results and expanded to the western states totalled $493K. The benefit/cost ratio thus formed is 77:1. Since only two major benefit contributors were used and since the forecast improvement estimate does not take into account future satellite capabilities these estimates are considered to be conservative.

The large magnitude of the benefit/cost ratio supports the utility and applicability of SATSCAM. Future development in the use of SATSCAM in computer models specifically tailored or adapted for snow input such as those developed by Leaf, Schuman and Tangborn, and Hannaford will most certainly increase the use and desirability of SATSCAM.

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