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CRITERIA FOR THE SELECTION OF  
WATER-RESOURCE PROJECTS

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## CRITERIA FOR THE SELECTION OF WATER-RESOURCE PROJECTS\*

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Estimates of the cost and gain attributable to water-resource projects (e.g., irrigation or flood-control measures) are often used to help winnow out the ones that should be undertaken. This sort of comparison, which is usually called "cost-benefit analysis," is closely related to systems analysis and operations research; all of these activities pose problems of formulating analyses and devising tests of preferredness. In this connection, three points are discussed and illustrated: (1) With a given water-resource budget, maximization of the present value of net benefits is a better test than the maximization of the conventional benefit-cost ratio. (2) The alternatives that are compared should be water-resource "systems" -- each consisting of a proposed project added onto existing watershed features and projects. As new projects are approved and constructed, the other proposals added onto the original watershed features may no longer be the relevant alternatives. (3) The alternatives that are compared should include project-increments, not just huge "lumps."

~~One fairly important problem of choice which the government faces~~  
is that of selecting water-resource developments -- such as navigation, flood-control, and soil-conservation measures, -- ~~that are to be undertaken each year.~~ The importance of the problem is indicated by the extent of current and potential expenditures on such water-resource projects: each year from \$1 to \$2 billion are now spent on water-resource development by the Federal government alone, and over the next generation, according to estimates in the Report of the President's

~~This paper consists mainly of excerpts from a study of the use of analysis to increase efficiency in water-resource development, and in other government activities. The study is intended for publication, and copyright is held by The RAND Corporation. The paper was presented at the Seventh National Meeting of the Operations Research Society of America in August, 1955.~~

Water Resources Policy Commission, from \$70 to \$100 billion may be spent on such developments.

In formulating the water-resource program, government makes use of "cost-benefit analyses," in which estimates of the costs and returns from each project are prepared. Such estimates have been made, for instance, for the Santa Maria project in California, a proposed combination of irrigation and flood-control measures about 130 miles northwest of Los Angeles. This example will be drawn upon to illustrate several subsequent points.

In the use of these estimates to help compare alternative water resource projects, the criterion that is supposed to indicate projects' relative merits is the ratio of benefits to costs. (For example, this ratio was calculated for the Santa Maria project, turning out to be 1.87 to 1.)<sup>1/</sup> If the ratio is higher than unity, a project is said to be economically justified. Moreover, in general, the higher the ratio, the more favorably a project is looked upon. In this way, this criterion helps determine both the size of the government Agencies' water-resource budgets and the particular projects that are to be undertaken with those budgets.

#### I. COST-BENEFIT ANALYSIS AND OPERATIONS RESEARCH

It is pertinent to note that cost-benefit analyses are closely related to operations research and to systems analysis. First, all such research provides assistance, much of it quantitative, in handling some problem of choice. More specifically, in all such research an attempt is made to trace out significant consequences of alternative policies that might be chosen. Operations research sometimes compares the

consequences of adopting alternative inventory policies in a business firm; systems analysis sometimes compares the implications of developing alternative weapons systems; cost-benefit analysis compares the consequences of choosing alternative sets of water-resource projects.

Second, in tracing out these implications, all these types of analysis are likely to use rather complex models, or sets of relationships, so as to reflect the effects of interdependencies. One of the main features which sets operations research apart from intuition or very crude analysis is the effort to take complicated relationships into account -- such as the connections between inventory policy, speed of delivery, customer satisfaction, variations in output, and manufacturing costs. In systems analysis also, relatively broad systems are compared in order not to neglect the way that a change in one part of the system affects the cost or performance of other parts of the system. Similarly, cost-benefit analysis makes use of some rather intricate models in order to trace out the consequences of various projects.

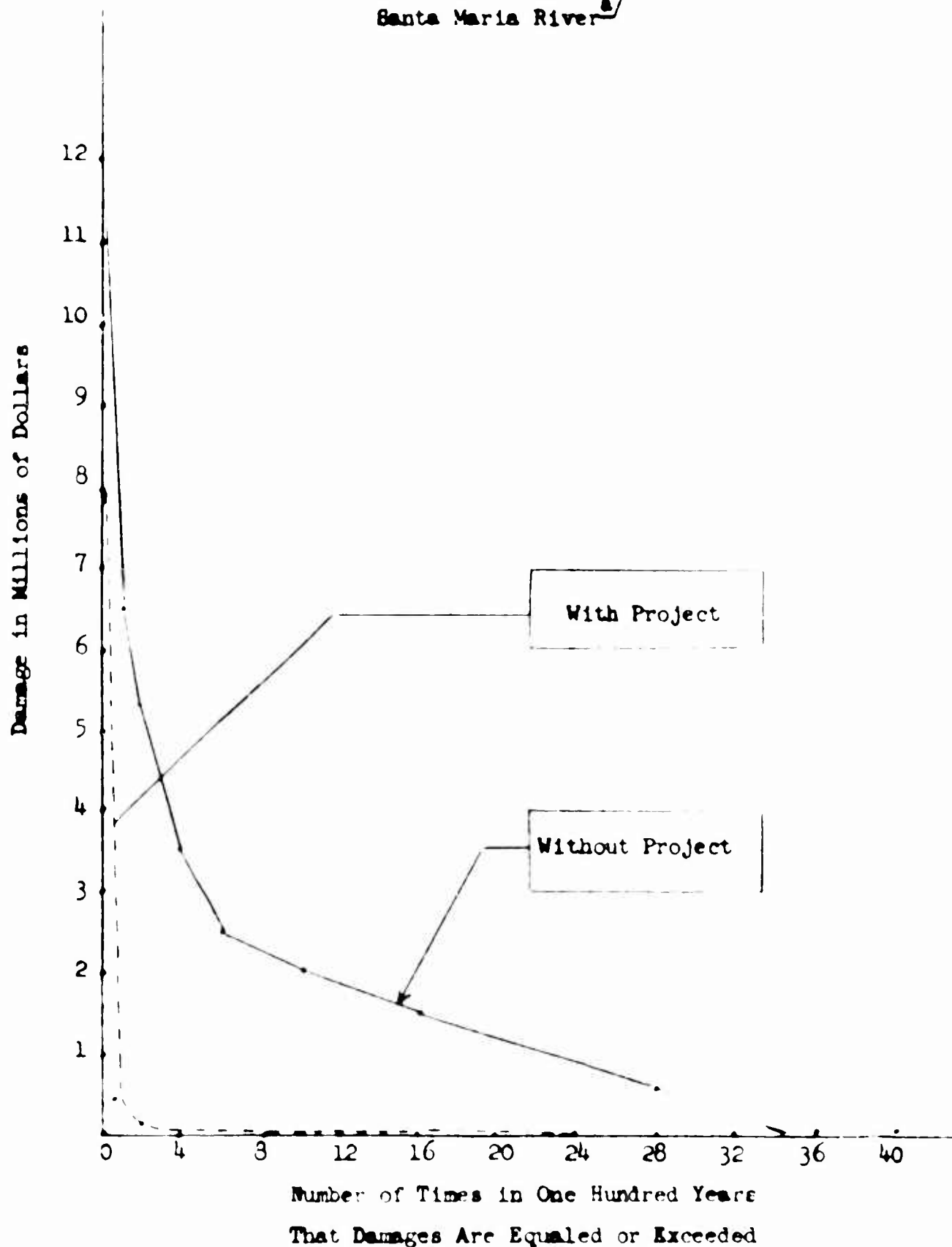
For example, with the Santa Maria project, stream flow below the reservoir would become a steady trickle instead of an intermittent scouring flood, one effect of which would be to raise the cost of channel scouring and maintenance. As another illustration, the use of some reservoir capacity for flood-control would affect the payoff from another component, the system of levees. That is, if one part of the system did part of the flood-control job, it would reduce the payoff from the other flood-control measures.

It may help convey the flavor of cost-benefit analysis if one part of the model used in the Santa Maria analysis is sketched out.<sup>2/</sup> In describing the effects of flood-control works, the analysts started with

the impact of these measures on stream flows -- that is, on the cubic feet discharged per second at designated points. They then proceeded to translate this information into estimates of damage-reduction attributable to the project. First, they worked out estimates of the damage that would occur without the project. From past records, a discharge-frequency curve was derived, showing the number of times one could expect various peak discharges to occur during a period of a hundred years. Next, a discharge-damage curve was prepared, showing the way average monetary damage over the coming decades was expected to vary with flood-size, measured as before by peak discharge. From these two curves, a damage-frequency relationship was obtained. Since the discharge-damage curve showed an estimate of monetary damage for each peak discharge, a damage estimate could be substituted for each peak discharge. Hence, the discharge-frequency curve could be translated into a damage-frequency curve. The last-named curve (in cumulative form, which shows the number of times that each damage figure would be equaled or exceeded) is the solid line shown in Figure 1. The area under this curve represents total damage over a 100-year period. This amount could be approximated by multiplying by one the damage expected to occur one time, multiplying by two the amount expected to occur two times, and so on, and then by summing up all these results. Expected damage per year is simply the total projected for the entire period divided by 100.

A similar procedure yielded a damage-frequency curve, and estimates of annual flood-damage, with the project -- i.e., with the reservoir, levees, and channel improvements that were being considered for the Santa Maria valley. This curve is the broken line shown in Figure 1. The average annual reduction of flood-damage attributed to the project

Figure 1. Damage-Frequency Curves  
Santa Maria River<sup>a/</sup>



<sup>a/</sup> Source: U. S. Army Corps of Engineers, Appendixes to Accompany Report on Survey, Flood Control, Santa Maria River and Tributaries, California (mimeographed), February 10, 1953, Appendix 5, Plate 4, following p. 19.

was then simply average annual damage without the project minus average annual damage with the project.

The purpose in presenting part of the Santa Maria model is simply to convey at least a brief notion of cost-benefit computations. In larger watersheds, the calculations get more complicated, as inter-relationships multiply: thus, on the one hand, a new reservoir upstream may stabilize the downstream flows and increase the firm power output that can be produced by downstream hydro stations, whether public or private; or, on the other hand, if water is used for irrigation, it may reduce downstream flows and the power output of downstream hydro stations. To repeat, the aim here is simply to convey some of the flavor of cost-benefit calculations and to indicate that they are similar to some of the estimation procedures that are used in connection with other problems of choice. In other words, cost-benefit analysis may be regarded as a type of operations research.

## II. GENERAL FORM OF THE CRITERION

As mentioned above in the description of cost-benefit analysis, the merit of each water-resource project is gauged traditionally by the ratio of benefits to costs, both converted to an annual basis. Now naturally this ratio is not regarded as the only piece of information which is relevant to these decisions. A great many objectives and political pressures enter into the actual selection of projects. Nonetheless, this criterion seems to play a leading role in the formulation of the water-resource program.

Or, more accurately, it plays a misleading role. This could be brought out by an examination of the Santa Maria project, but this

particular point can be shown more simply if we compare two hypothetical projects, A and B. First, some preliminary definitions: benefits are the value of a project's output -- equivalent to a firm's sales -- and costs are costs -- the amounts that must be given up, or spent, in order to buy the project. Both costs and benefits are streams over time, of course, and in order to be compared properly, these streams would have to be discounted carefully in order to derive their present values or to put them on an annual basis. For the sake of convenience and ease of manipulation, the calculations here will be greatly oversimplified.

As shown in Figure 2, each of the two projects (A and B) requires the investment of \$10 million to be written off in 10 years. A has

Figure 2. Conventional Criterion for Ranking Two Projects  
(amounts in millions of dollars)

		<u>A</u>	<u>B</u>
Investment		<u>\$10</u>	<u>\$10</u>
Annual Benefits		15	5
Annual Costs			
Operating	4		0
Depreciation	<u>1</u>		<u>1</u>
Total		<u>5</u>	<u>1</u>
Ratio of Benefit to Cost (Annual)		3/1	5/1

operating costs of \$4 million, annual depreciation of \$1 million, total annual costs of \$5 million, and total annual benefits of \$15 million.

Hence, the ratio of annual benefits to annual costs is 15 to 5, or 3 to 1.

B has no operating costs (obviously an extreme example), annual depreciation of \$1 million, total annual costs therefore of \$1 million, and total

annual benefits of \$5 million. Thus, the ratio is 5 to 1. According to current practice, B is to be recommended because its ratio is higher. Yet, as indicated in Figure 3, its net "profit" over the period is only

Figure 3. New "Profits" from the Two Projects

	<u>A</u>	<u>B</u>
Annual Benefits	\$15	\$ 5
Annual Costs	<u>- 5</u>	<u>- 1</u>
Net Profit Each Year	10	4
Net Profit Over Life of Project (10 Years)	100	40

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\$40 million (10 times \$5 minus \$1) while A yields \$100 million (10 times \$15 minus \$5) all for the same investment. A clearly adds more to our present worth, and is surely the better investment.

What's wrong with the ratio? Well, it's the ratio of gross benefits to gross costs. The equivalent criterion in business would be the ratio of receipts to expenses. If this sort of test were used in business, entry into retail trade, or any venture involving a high turnover, would appear to be foolish, because the ratio of gross sales to expenses, or the rate of return on sales, would be comparatively low. Yet the profit on the investment might be relatively high. What ultimately matters is not the ratio of gross sales to expenses or rates of return on sales; if a venture promises annual sales of \$102 million and annual expenses of \$100 million (i.e., 2 per cent on sales), it may still be anything from a bonanza to a dud. What matters is the profit on investment, or more precisely, the prospective change in present worth.

Similarly, the most significant test in public investment -- wherever measurable benefits and costs are important -- is surely not the ratio of gross benefits to total costs. This provides no basis for doing what governmental agencies must usually do -- that is, judge the relative merits of different projects whose benefit-cost ratios are greater (or less) than unity. If the conventional ratio is used for this purpose, a project that has high gross returns and operating costs will be at a relative disadvantage, whatever its potential contribution to present worth. This may seem to be an elementary sort of error. It is stressed here because this error is being made when ratios of sales to expenses (i.e., benefits to costs) are used by Congress or within the Departments. And, incidentally, it is a type of error -- the use of the ratio of gain to cost as a criterion -- which sometimes occurs in other pieces of operations research and systems analysis.

As in the case of private investments, what ultimately matters is surely the profit on investment, or more precisely, the increase in present value that can be obtained with any investment budget. It is not necessary for present purposes to ask just what discount rate should be used in order to estimate the increases in present values: the answer would depend upon the way in which capital is "rationed" to government and to government agencies. The essential point here is that we should choose those investments which yield the greatest benefit minus cost, not those which yield the highest ratio of benefit to cost.

### III. CRITERION MISLEADING IF WRONG ALTERNATIVES COMPARED

Even if the appropriate test of preferredness is adopted, it will not reveal the best policy if the wrong alternatives -- water-resource

systems in this paper -- are being compared. This is a commonplace observation, but two particular situations in which the wrong alternatives may be compared are worth special mention here.

#### A. Comparison of Systems That Have Been Modified Since Original Analysis

As mentioned previously, on account of interdependencies, we often have to compare rather broad systems. That is, in order to compare ventures (or weapons, or production schedules) A, B, and C, we really have to compare rest-of-the-system-plus-A, rest-of-the-system-plus-B, and rest-of-the-system-plus-C. To see this more clearly, suppose that a project consisting of specified levees, channel-improvements, and reservoirs is A, and other sets of proposals in the same broad watershed are B and C. The rest-of-the-system in each case encompasses existing man-made features (reservoirs, flood-control structures, power projects, industrial establishments) and natural features (climate, land, forests) which would affect, or be affected by, the operation of the proposed project. Thus, the full systems whose performance should be compared comprise in each instance the whole complex of features that already exist, or are taken as given, and those that are proposed. As a practical matter, of course, we draw a line somewhere, considering only features of the basin or watershed which are deemed to be involved "significantly."

The comparison of such systems is helpful if we are to choose only one of these ventures (A or B or C) and then forget about the other two. But there may be trouble ahead if we try to rank A, B, and C for future reference. And this is exactly what we sometimes do attempt in the analysis of water-resource measures -- that is, to evaluate the projects and then to use the evaluations at considerably later dates.

The reason that there may be trouble is that the outcome of A may depend upon whether or not B is in existence, and vice-versa. In other words, as soon as one of the projects is to be constructed, the earlier evaluations may no longer be applicable. In that circumstance, the ranking based on the earlier evaluations may be wrong. For instance, suppose we compare the watershed (including whatever measures exist or are taken for granted) plus a reforestation project, the watershed plus a forest-fire control program, and the watershed plus downstream levees. Suppose the reforestation project turns out to be best, and it is to be carried out. Perhaps the downstream levees are second-best according to the initial analysis. Will they continue to be second-best? Not necessarily, because reforestation will decrease water runoff and hence the benefits to be obtained from levees (a "competing" project) and increase the gains to be obtained from forest-fire control (a "complimentary" project).

In other words, strictly speaking, our conclusions pertain only to the systems actually compared, and not necessarily to modifications of those systems. The alternative systems that were examined in last year's analyses may not be the ones which should be compared in order to select next year's projects. We may use the original analyses as the basis for views on modified systems -- i.e., we may assume there are no significant interrelationships between projects A, B, and C, and use the initial ranking as though it were independent of the construction of A, B, or C; and in some cases this will be justified, but what is being assumed should be recognized.

#### B. Comparisons of Project-Lumps vs. Project-Increments

It has been repeatedly suggested that, on account of interdependencies, the way to come to grips with the true gains and costs, and hence with the

proper criterion, is often to compare broad systems. In the case of water-resource development, this means looking at entire watersheds or river basins. It should be emphasized, however, that the proposed measures in various river basins need not, indeed should not, be examined as indivisible lumps. It is important to break these proposed measures down into parts and see whether successive increments are worth their cost. Thus the systems that are being considered should embrace several combinations of components -- such as existing features of the watershed plus extra forests, existing features plus forests plus terraces, and then all those components plus channel-improvement. Also, the measures that are being considered should embrace several sizes -- such as 50,000 miles of terraces, 100,000 miles of terraces, and perhaps a third size. Then, in the context of the system and given the other components, we should ask: what are the extra costs and extra benefits attributable to each major feature or to each major increment in size? Only in this way can we show whether or not uneconomic features or uneconomic additions in size are riding in on the coattails of the truly profitable parts of a proposal.

The Santa Maria analysis, prepared jointly by the Bureau of Reclamation and the Corps of Engineers, is better than many others in this respect, for considerable attention was given to the costs and gains of alternative development plans, e.g., reservoirs with different capacities and at different sites. However, still more effort of this sort was probably warranted. For example, it would have been in order to exhibit the consequences of adding the levee system, given the reservoir (see Figure 4). According to the official estimates, the extra costs due to including this feature amount, on an annual basis, to \$448,000.<sup>3/</sup> (In another place,

Figure 4. Analysis of Project Increments  
(Levees and Channel Improvement, Santa Maria Project)

Extra Annual Cost Due to This Feature	\$448,000
Extra Annual Benefit (Reduction of Flood Damage)	
Reservoir Plus Levees, Channel Improvement	\$600,000
Reservoir Alone	<u>200,000</u>
Addition of Levees, Channel Improvement	\$400,000

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this cost is stated to be \$576,000.<sup>4/</sup> What is the extra benefit attributable to the channel-improvements? This benefit arises solely from the reduction of flood damage. The reservoir plus the channel improvements would produce flood-control gains, on an annual basis, of \$600,000 (again the official estimate).<sup>3/</sup> If a new damage-frequency curve, given the reservoir alone, is prepared,<sup>\*</sup> it suggests that the reservoir by itself would yield annual gains -- that is, flood-damage reduction -- of at least \$200,000 (the writer's calculation, as no official estimate was located). Hence, the addition of the channel-improvement would lead to extra annual benefits of \$400,000. It is worth noting, incidentally, that this benefit is less than the annual gain that channel-improvement alone would produce (\$500,000), because if this feature were added onto the reservoir, the operation of the reservoir would already do some of the flood-control job. As a part of this package, however, this feature would not pay its way according to these rough estimates; yet it is the package that is analyzed in the official project report, and the channel

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<sup>\*</sup>This curve, though not shown in Figure 1, would lie between the two curves that are presented there.

improvements are not examined as a separable feature.

Now it is not suggested that separable project increments can somehow be analyzed outside of the system of water-resource measures. It is necessary to fit whatever alternatives are being examined into the watershed along with its existing features and to recognize interdependencies in calculating benefits and costs. But -- and the point is worth this repetition -- the relevant alternatives to be considered should include several combinations of the components -- such as reservoir capacity for irrigation alone, reservoir capacity for irrigation and flood control, reservoir capacity for irrigation and flood control plus channel improvements. Also, the alternatives that are being considered should include several sizes -- such as a reservoir that would cost \$15 million, one that would cost \$20 million, one that would cost \$25 million. Thus, while the system into which the proposed projects are fitted may need to be broad, the project increments and variations whose merits are being considered should not always be great lumps.

In conclusion, let me add that the points made here are exceedingly simple -- yet, I think, important. They are that in cost-benefit analysis, as in any operations research, criteria that are devised carelessly can be quite misleading, and that even appropriate criteria will not lead us to proper policies if the wrong alternatives are compared or if relevant alternatives are overlooked.

- 1/ Bureau of Reclamation, Santa Maria Project, California, House Document No. 217, 83rd Congress, 1st Session (U. S. Government Printing Office, 1953).
- 2/ Sources: Bureau of Reclamation, op. cit.; the Corps of Engineers, Report on Survey Flood Control, Santa Maria River and Tributaries, California (micrographed), February 10, 1953.
- 3/ Bureau of Reclamation, op. cit., pp. 4-10.
- 4/ Corps of Engineers, op. cit., pp. 44-45.