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THE ECONOMIC COMPARISON OF HYDROELECTRIC PROJECTS WITH ALTERNATIVE DEVELOPMENTS OF THERMAL ELECTRIC POWER

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Introduction

1. The essence of the economic evaluation process is determining whether a project involves a better use of resources than its possible alternatives. In many cases the alternatives themselves may not be clear and the comparisons have to be approximated. This is the purpose of using a minimum rate of return as representing what capital might earn in alternative uses, or what is known as the "opportunity cost of capital". If a project is expected to yield less than this minimum, it should not be undertaken for there are presumably more productive uses for capital elsewhere. The case where specific alternatives are under consideration representing different ways of producing the same good or service whose need is given is a special type of this general problem. In this case the immediate comparison is clear. The choice is limited to the given alternatives, one of which must be selected. The "opportunity cost of capital" comes into the problem in helping to determine which of the alternatives involves the most economical use of resources in the light of general investment opportunities in the economy.

2. An excellent example of this special type is the comparison of alternative methods of producing electric power. A KWH is a KWH, whatever way it is produced. The question is which method of generation is the cheapest. This is an important problem in practice since it is at the basis of the economic appraisal of all hydroelectric projects. In some cases the answer is obvious. The cost of fuel may be very high and the cost of constructing hydro plants very low. In important cases, however, more detailed analysis of the alternatives may be essential to the appraisal and although the problem of determining the least expensive solution may be simple in concept, the analysis itself may not be so.

3. It is the purpose of this paper to set down in a systematic way a logically correct method for handling the economic comparison of alternative power developments. The discounted cash flow method of computing returns which is used here has come to be generally accepted in recent years. There is no need to give a detailed justification of this approach at this date; that has already been done most competently by others. 1/ However, there is merit in working out an example of a specific and important application. By focussing on the technique itself and pointing out ways in which the analysis may be simplified this paper may be of particular use to others faced with similar appraisal problems. It should go without saying that the less an appraisal mission has to concern itself with problems of method, the more it can concentrate on the essential aspects of its analysis.

1/ See, for example, "Project Evaluation I, The Return on Capital", B.B. King, EDI Seminar Paper, 1960; Principles of Engineering Economy, E.L. Grant and W.G. Ireson, N.Y., 1960; Water Supply, Economics, Technology and Policy, J. Hirshleifer, J.C. DeHaven and J.W. Milliman, Chicago 1960. (See especially Chapter VII.)

4. Furthermore if the method is well understood and if some preliminary appraisal has already been made by consultants, the sensitivity of the results to changes in key data can be worked out in advance so that effort in the field may be concentrated on the most critical items. If lack of provisional data prevents this, the same procedure can be applied to the mission's own preliminary results, so that critical variables may be pinpointed at this later stage and subjected to further scrutiny. In any case such analysis is required to determine under what conditions, if any, the project is justified. This is particularly important if estimates of future developments have to depend on decisions which have still to be made and which could materially affect the attractiveness of a project.

5. This paper deals with the specific problem of comparing alternative developments of a power system to supply a demand for power (KW) and energy (KWH) that must be met.1/ It is essentially a comparison of a hydro with a thermal system of development. However, the method employed need not necessarily be confined to comparisons of power projects. Any possible set of alternatives could be compared and in fact the method could equally well be applied to any number of alternatives.

6. To make the demonstration realistic the data used in this paper are in large part based on the preliminary work sheets of an actual project. The following section briefly discusses the application of discounted cash flow methods to a comparison of hydro and thermal system developments, with special reference to the appropriate length of the cash flow. It is followed by an analysis of the effect of variations in cost estimates on the results of the calculations. The final part deals with the effect of different patterns of growth of demand for power on the economic appraisal of the project.

A. Comparison of hydro and thermal power alternatives: General shape of the problem

7. In comparing alternative ways to produce the same output, the economic selection problem is simply to determine which way is the cheapest. In the particular problem under consideration, it is assumed that the demand for power should be met.2/ The question is not whether to invest in power or in some other sector but rather which type of power investment represents the best use of resources, given the decision to invest in power. In other words, benefits from the investment however measured are the same regardless of which system of development is chosen, only the costs are different.

1/ In the case considered here it is assumed that there are no irrigation, navigation or flood control benefits associated with the hydro project. Where this is not the case the problem of analysis is more complicated since the investment cost of the hydro power cannot be determined simply.

2/ Techniques of estimating future demands for power, and of designing corresponding system developments, are not discussed here. This paper is concerned only with the analysis of the data thus obtained.

8. The comparison of costs between the two alternatives is not straightforward, as alternatives have decidedly different patterns of expenditures over time. Typically the hydro alternative will involve higher expenditures in the early years and the thermal alternative higher expenditures in the later years. In a simplified way, the choice can be stated in terms of whether higher investment costs of hydro in the early years are or are not justified by its lower operating costs in the later years.1/ The only way a proper comparison can be made between series of expenditures with different time patterns (cash flows) is by making specific allowance for the time factor and summing them up as of a particular point in time. This is accomplished by discounting the two cash flows to a common year. The sum of the discounted values, that is the "present values", can then be compared directly. This procedure involves three types of decisions - what is to be included in the costs or expenditures, over what length of time should the computations be extended, and what interest rate should be used for discounting.

9. In the calculation of costs only actual expenditures on goods and services should be included and these should be entered in the year in which they occur. Financial charges and accounting items, such as interest, depreciation and amortization, should be excluded. Depreciation and interest on capital investment are taken into account by the discounting procedure itself. Amortization and interest on loans are financial items dependent on specific terms of financing and not inherent in the nature of the project. They are not relevant for the economic appraisal.

10. The length of time over which the cash flow should be extended depends on circumstances, and falls into two parts. The first period covers the years of expansion of the system. This should be continued until the year whereafter the relative costs of alternative ways of further expanding the system is no longer significantly prejudiced by the investment decision now taken. This delineates the alternative system developments to be compared at this time. Often this will be the year of full utilization of the power capacity of a hydro dam.2/ For the purpose of calculating the return on additional hydro investment, expansion of the system stops in this year. The cash flow, however, should be further extended, for a second period which should extend until differences in costs of operating the alternative systems at the constant level reached become insignificant in terms of their discounted present worth. These costs involve not only expenses for full maintenance and current operation, but also for replacement investments, the latter being entered in the year in which they fall due. This applies to necessary replacement both of existing plant and of new plant installed during the expansion period. Replacement does not necessarily consist of exactly the same units as previously installed. It may be more reasonable to replace them by units of a larger size, more appropriate to the level of output reached in the meanwhile. For thermal plant, lifetime

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1/ This is illustrated in Chart 1 for a complicated and realistic case; see paragraph 14 below.

2/ This is not necessarily so. Building the dam may make possible a later second stage of the project - or construction of a dam elsewhere in the same river system, providing cheaper additional power than from alternative thermal plants. As long as the present investment decision significantly influences such later investment choices, the expansion of the system should be extended for purpose of appraisal.

is usually taken to be 30 years and for hydro plants 60 years. Life of dam and reservoir may be longer still.

11. Finally, these flows of costs should be compared. The same answer may be obtained by different methods. One method is to find, by trial and error, the rate of discount which equalizes the present worth of the two cost streams to be compared. Alternatively, the same result may be obtained by deducting the thermal cost stream from the hydro cost stream, thus obtaining one stream of positive and negative items, as shown by the dotted line in Chart 1. The positive items are the additional costs of the hydro alternative, and occur mainly in the earlier years; the negative items are the savings in cost of the hydro alternative ("its benefits"). The discount rate which equalizes the present worth of the positive and of the negative items will be the same as the one which equalizes the present value of the two separate cost streams and may be thought of as the rate of return on the additional (initial) investment in the hydro alternative.

12. The rate of return thus obtained should be compared with the estimated opportunity cost of capital (the so-called shadow rate of interest) in order to assess whether the return is adequate. Alternatively, this same rate (opportunity cost of capital) may be used to obtain the present worth of the cost streams of the two alternatives. The alternative with the lowest cost, in terms of present worth, should be considered the better project.

B. Impact of variations in costs and prices on return on additional hydro investment

13. The foregoing exposition has been concerned only with the form of the calculations. It assumes that all the necessary data on costs and markets are given. In actual appraisals, however, the available data are often incomplete and always of varying quality. For some items, reliable cost estimates may be relatively easy to obtain; for others, data may simply not exist. In some cases, it may be possible to relate the projections of demand to firmly-based future trends in its main determinants; in other cases this may not be so, especially if the future demand is expected to be heavily dependent on particular investments in power intensive industries, which may or may not take place at a given time. Furthermore, the cost of foreign exchange may be undervalued and the cost of labor overvalued in terms of their real cost to the economy. Thus the appraisal must be made on the basis of data with widely differing degrees of reliability. It is necessary to appraise the data, improve them where possible, organize them so as to give an answer within the limits of their accuracy, and so come up with a judgment on the overall economic merits of the project. It is thus obviously important to be able to determine the effect of variations in the main cost and demand parameters of the problem on the overall outcome; only then can efforts of estimation, and necessary judgments, be focused on the most critical elements of the appraisal. This part of the study (B) will consider ways of estimating the impact of variations in costs. The influence of different demand patterns will be taken up in the final part (C).

Use of sub-cashflows for cost components

14. Tables 1 and 2 show detailed cash flows for the hydro development and thermal development,1/ respectively, both to meet the "lower" load.2/ The column "total", represented in Chart 1, is the only one required for calculating the return on the higher initial investment necessary in the hydro development. As will be noted, the present worth of the cash cost streams of both hydro and thermal development are about 1260 thousand, when discounted at 7½%. This indicates that the return on the additional hydro investment is 7½%. For a convenient check on the extent to which this outcome is altered if some of the cost items were different, the cash flows can be broken down by components as shown in Tables 1 and 2. The degree of disaggregation, and the categories of cost selected, depend upon the particular case to be investigated but, as a minimum, such items as dam, hydro units, thermal plant and fuel costs should be specified. The various sub-cashflows, for each of the cost components, are then discounted at 7½%. The results are shown at the bottom of Tables 1 and 2, and summarized in Table 5. The present worth has been calculated separately for costs occurring in the period 1962-1980 (the expansion period) and 1981-2028 (the constant period). Thus it is possible to distinguish the influence of costs occurring in either period on the return obtained.

15. Tables 1 and 2, and summary Table 5, also show the present worth of the cost flows if discounted at 8½%. Normally at least two calculations at different discount rates have to be made in order to arrive, by trial and error, at the rate which equalizes the present worth of the costs of the alternatives. These calculations also give a rough indication of what is a "significant" change in the underlying cost estimates. Table 5 shows, for example, that a difference in discount rate of one per cent (between 7½ and 8½%) results in a difference of "70" in the total present worth. By crude linear interpolation this indicates that a difference of "35" in present worth is equivalent to a change of one-half of one per cent in the rate of return for variations around 8%.

16. From Table 5, it is apparent that the outcome depends heavily on the present worth of the cost estimates of the dam, hydro units, thermal plants, fuel, and possibly operating cost of production plant. For instance, a 20% reduction in the cost of the dam would change the return on the hydro investment by about one percentage point. A rise of close to 30% in the fuel price would have the same effect. It should be noticed that the "weights" - i.e. the present worth of the various cost items - decline at higher discount rates, so that somewhat greater percentage changes in costs are necessary to produce a change in the return of, say, one percentage point, than those indicated by the present worth figures obtained at 7½%. The effect is small, however, for small changes in the discount rate, except for items such as fuel costs where a large part of the difference in present

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1/ Hydro development and thermal development refer to alternative <u>system</u> developments; the hydro alternative does, in fact, include some use of thermal plants, as may be seen from Table 1.

2/ A more rapid growth of demand for power - the "higher" load - is discussed in part C below; cf. Tables 3 and 4.

worth between hydro and thermal alternatives occurs in the later years (1981-2028). Some of the other items - for example, the operating cost of the transmission lines - are small so that even a 50% change in the estimate affects the total present worth (and the return) only marginally. Others, such as investment in transmission (230 kv) and frequency conversion, are substantial, but any change in the cost estimates affects the thermal and hydro alternatives almost equally. Similarly the possible impact of under- or overestimation of the large item "operating costs of production plant" may be much reduced by offsetting changes for both alternatives.1/

17. Offsetting items, in terms of present worth, may obviously result simply from the same item occurring in the same year in the basic cash flows of both alternatives. In practical application, such items would have been eliminated beforehand, (that is, before making the present worth calculations) in order to economize on computing time. Comparison of Tables 1 and 2 will show that this would eliminate columns "transmission 115 kv" and "frequency conversion", and a good many items in the columns "transmission 230 kv" and "thermal plant".2/ Items of the same order of magnitude in the same year will similarly (largely) cancel out. Offsetting items in terms of present worth may also result, however, from the discounting process itself. Thus the difference in fuel costs is much reduced by the fact that costs are roughly the same for both alternatives in the early years and only differ greatly later on.

Impact of different cost estimates

18. Costs different from those shown in the basic cash flows of Tables 1 and 2 may be due to under- or overestimation of physical inputs required, and/or of prices of inputs. Amongst the physical inputs, it is especially difficult to estimate accurately the input requirements of the dam. Difference of opinion is also possible on the fuel efficiency of thermal plants and other items. It will be clear by now, however, that the quantitative significance of such differences can easily be analysed by reference to Table 5. If, for example, the operating costs of thermal plant (excluding fuel) had been systematically underestimated by 25%, their present worth at 7½% would have to be adjusted upward by 25%, and this would be equivalent to an increase of about 1% in the true return on hydro investment. It also becomes easy to see, for example, that under-estimating labor efficiency in thermal plants by 20% in the period 1962-1980, and overestimating it by 10% in the later period 1981-2028, would result in raising the return by close to one-half of one per cent.

19. Similarly, one can easily investigate the effect of using prices other than those used in the basic cash flows. There is bound to be some uncertainty in the estimates of future market prices. The analyst may also wish to determine the effect of using so-called shadow prices - for example, for foreign exchange, wage rates, fuel, etc. - if he has reason to think that market prices do not give a reasonable approximation of

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1/ This is true if the under-estimate is due to the wage rate, affecting both alternatives. The error may be due, however, to different efficiency in use of labor in thermal plants, affecting mainly the thermal alternative (see below, paragraph 18). The same composite item "operating cost of production plant" in the cash flow of both alternatives is somewhat misleading as it refers largely to different costs - for thermal plants and hydro plants respectively. It would have been preferable to distinguish those in the cash flows.

2/ Cf. footnote 1/ above.

economic value to the country as a whole. To illustrate, what is the effect of a revision of the exchange rate downward by 20% on the return on hydro investment? The outcome depends, of course, on the foreign exchange component of the various cost items. Let us assume that in our example the foreign exchange components and thus the increases in costs resulting from lowering (devaluing) the exchange rate by 20% throughout the period 1962-2028, are as follows:

Item	Foreign exchange component	Increase in cost resulting from 20% lower foreign exchange rate
	per cent	per cent
Dam	50	10
Hydro units	80	16
Thermal units	75	15
Transmission	80	16
Other	0	0

20. The cost of the hydro alternative in terms of present worth at $7\frac{1}{2}\%$, therefore, will rise by 10% of 331 (dam) plus 16% of 265 (hydro units) plus 16% of 105 (additional transmission) = 91; and the cost of the thermal alternative (in terms of present worth), will rise by 15% of 361 (additional thermal plant) = 54. Thus the relative cost of the hydro alternative goes up by 37, and the return on investment in hydro goes down by about one-half per cent.

21. In similar fashion one can investigate whether a shadow wage rate for unskilled labor makes much difference to the return on the hydro investment. If, for example, unskilled labor amounts only to 2% of the total cost of the dam - which is an actual though probably extreme case - an adjustment in the wage rate can at most lower the cost of the dam by 2% - with a negligible effect on the return. In such a case it is, therefore, not necessary to devote time and energy to trying to find a proper value for the shadow wage rate of unskilled labor.

22. The question may also arise whether the market price for cement is appropriate for the economic evaluation of the alternatives. Large overcapacity in a local cement industry may argue for using a lower price. Is this significant? Once again, it depends upon the "cement content" of the dam. If this is, say, 8%, a $12\frac{1}{2}\%$ reduction in the cement price lowers the dam costs by one per cent, i.e., an insignificant amount. Relatively small adjustments in the cement price are therefore irrelevant. Even a 50% reduction in the cement price results only in 4% lower dam costs, and an increase of less than one-quarter of one per cent in the return on the investment in the hydro alternative.

23. Thus the order of magnitude of the impact of various adjustments in input prices on the return can be established. This kind of analysis brings out whether further refinement of the estimates made is worthwhile or not. Adjustments so small as not to affect the return calculation are irrelevant, and the analyst is better employed trying to estimate the crucial variables.

24. As already pointed out above, one of the crucial variables in hydro/thermal comparisons is the price of fuel. In this particular case a 15% change upward or downward in the fuel price changes the return of the hydro investment by approximately one-half of one per cent. The form of the analysis also permits experimentation with more complicated changes in fuel prices, varying over time.1/ If there is reason for thinking that fuel prices will later, say, from 1981 onward, be higher or lower than at present, the quantitative significance of this can easily be established.2/ Present fuel costs to the economy may be low because of overcapacity in fuel production itself or in transport facilities. In due course, overcapacity may disappear, or alternative uses may develop for a fuel such as natural gas, and a higher price may become appropriate. The present analysis can show how sensitive the return on the hydro investment is to such changes in fuel prices.

C. Impact of different growth of load on return on additional hydro investment

Higher load - actual case

25. The return on the hydro investment will tend to be higher, of course, if the capacity of the dam can be fully utilized at an earlier date. The initial capital costs of the dam will then weigh less heavily on the hydro alternative. This is illustrated in Tables 3 and 4, which are similar to Tables 1 and 2 except that the system development is geared to a more rapid rate of growth of the power load. As a result, the capacity of the dam is fully utilized by 1979, and not by 1981 as in the previous example. Consequently the return on the additional hydro investment is somewhat higher, about 8¼%, as will be seen by comparing the figures for present worth of total cost, at 7½% and 8½% respectively, shown at the bottom of the tables.

26. Comparison of the present worth of cost components for the "higher" and "lower" load system development (summarized in Table 6), indicates more precisely the reason for the greater return with the "higher" load. With more rapid growth of the load, the present worth of costs of hydro units rises somewhat for the hydro alternative, and the present worth of costs of thermal plant rises rather more for the thermal alternative. Operating expenses of production plant increase slightly for both alternatives, but largely cancel out. The most important difference, however, is the increase in fuel costs in the thermal alternative, offset only to a minor extent by an increase in fuel costs for the hydro alternative. The relative increase in fuel costs with "higher" load growth accounts for more than two-thirds of the total relative increase in cost (in terms of present worth) of the thermal alternative.

1/ In fact, the basic data used in this note, incorporate such changes in fuel prices over time.

2/ In our example, this is only convenient in two periods, 1962-1980 and 1981-2028, but a further breakdown by periods could, of course, easily have been provided.

27. From the general set-up of the problem - see paragraph 10 above - it might be thought that the period from 1981 onwards does not play any role in these differences. It will be remembered that in the "higher" load growth variant, the system is kept at a constant level (for purpose of return calculations) from 1979 onwards, the year in which full capacity of the dam is reached. And similarly, from 1981 onward for the "lower" variant. There may be further complications, however. Reference to Tables 1-4 shows that, in our example, about half the difference in fuel costs between the higher and the lower load developments occurs in the period 1981-2028. This results mainly from the higher load factor which, in this case, is associated with more rapid growth of the load. In terms of MW the systems are the same, after 1981, but with the "higher" load growth it happens to require more KWH and, therefore, more fuel for the thermal alternative.1/2/ This effect is significant enough, in this case, to account for a difference of about one-quarter of one per cent in the return on additional hydro investment, between the higher and lower load curve (out of a total difference of about three-quarters of one per cent). A higher load factor is not an essential feature, however, of a faster rate of growth of the load. It depends on the reasons for the more rapid growth, i.e., on the growth of the components of the load. Conversely, different load factors may be associated with the same expansion of the load. A higher load factor tends, of course, to make the investment in the hydro alternative more attractive, as it raises the fuel costs of the thermal alternative while costs of the hydro alternative remain the same. The quantitative significance of this can be analyzed along the lines previously indicated. In the original example (Table 5), an increase in the load factor by, say, 14 per cent over the whole period 1962-2028, raises the fuel costs of the thermal alternative by 14 per cent - i.e., the return on the additional hydro investment by one-half of one per cent.

28. The "pure" effect of a faster growth of the load on the return on additional hydro investment is small in our example - about one-half of one per cent. Given the many uncertainties of the estimates involved, it would appear therefore that a delay of two years in fully utilizing the dam - 12 years rather than 10 years after the dam is finished - results in an insignificant difference in the return. In view of the fact that the underlying load projections used in this case show the "higher" load in 1980 to be more than 25% higher than the "lower" load, this may be somewhat surprising. The explanation is to be found in the shape of the curves representing the growth of the load. The following paragraphs use various heavily stylized examples to illustrate the effect of differences in load growth on the return on additional hydro investment.

1/ To a minor extent, the differences between higher and lower development are also due to the impossibility in the calculations of cutting off the expansion of the system at exactly the same point.

2/ A negligible difference results also from a slight shift forward in the replacement investments in thermal plant.

Stylized examples of different patterns of load growth

29. Chart 2 depicts the basic patterns of load growth used in these examples. In the case represented by Curve I, for example, the load rises from 500 MW in year zero ("the year of decision") to one thousand MW in year 5, in which the dam would be finished, and to 2,500 MW in year 25. Tables 7 (a-b) show simplified discounted cash flow calculations for hydro and thermal system developments fitting the various cases represented in graph 2. The dam is assumed to take 5 years to build, and to cost 1000 (all incurred for convenience sake in year 5); a hydro unit to cost 100, and a thermal unit 150. Additional cost (including fuel) of operating thermal plants rather than hydro units is assumed to be 1/15 per MW. Both thermal unit and hydro units are 150 MW. Total capacity of the dam is 10 units or 1,500 MW. Lifetime of a thermal unit is 30 years, of a hydro unit 60 years, and of the dam more than 60 years. The same basic cost and size assumptions will be used throughout the remainder of this paper, unless otherwise noted.

30. The present worth calculation shows that the return on investment in hydro is about 8% if the load grows as represented by Curve I (see bottom of Case I, Table 7). It should be noted that the return would also be 8% - as the cash flows would be exactly the same - if the load were to grow as in Curves Ia or Ib, their very different rates of growth notwithstanding. In Case Ia the load quadruples between years 5 and 25, and in Case Ib it only increases by two-thirds. Calculated from year zero, on the other hand, the rate of growth of Ib is much greater than that of Ia.[1] These differences in rates of growth are irrelevant, however; what counts is the absolute increase in the load from the year that the dam is finished, not from the time the estimate is made or the construction of the dam is started. In our example, the absolute growth of the load after year 5 determines the speed with which the dam can be "loaded".[2] The much greater absolute increase in Case Ib between year 0

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[1] Case I is intermediate in between these two extremes.

[2] The loading time of the dam does not depend solely on the growth on the load. Possible replacements of existing thermal plants may provide additional scope for using hydro power, and thus shortening the time needed for the dam to get fully loaded. The importance of this factor depends, of course, on the age structure of existing plant in year zero. Thermal plant installed during construction period of the dam (cf. 1/ p.11) only plays a role in this if the loading time of the dam is very long (more than 25 years); otherwise their replacement affects both the thermal and hydro development equally. The effect of "replacement load bonuses" on the return can be analyzed by simply adding them to the growth in the load derived from estimates of future demand for power.

and 5, i.e. during the construction period, does not help.1/ The absolute annual increases after year 5 are the same in all three Cases, I, Ia and Ib; hence, the same return on the additional hydro investment.2/

31. Obviously, it is not simply a question of the total "loading time", but also of the shape of the load growth curve. Curves I, II and IIa (cf. Chart 2) all show an increase by 1,500 MW between year 5 and 25.3/ However, investment in hydro is obviously more advantageous in Case II: discounted at 8% the present worth of costs of thermal power far exceeds that of hydro power. Experimentation shows that the internal rate of return is about 10%. Case IIa is obviously the worst - if it were decided to put in the dam immediately, although needed only 10 years later - with a return of only 6%. Case IIa is indeed a text book example of the need for postponing the investment: if construction is postponed by 10 years so that the dam is ready in year 15, the pattern of loading is the same as in Case II, and so is the internal return of 10% (i.e., higher than for Case I).4/

1/ Different rates of growth of load during the construction period affect, of course, the need for additional power capacity in the interim period. Our heavily stylized examples assume that this does not significantly affect the system development from year 5 onward. The faster rate of growth in the interim period is not necessarily an advantage; it may absorb existing excess capacity; it may also necessitate new investment in excess of load requirements in year 5.

2/ These considerations also caution against overestimating the influence on the return of an increase in the service area by interconnection. In comparing growth of the interconnected and the non-interconnected load, it should be noticed that the starting point of the former is higher. The gap between the two loads after, say, 10 years, overestimates, therefore, the difference in their absolute increases by this difference in starting level. The higher starting level broadens the base, of course, so that any given rate of growth of the load results in a larger, absolute increase.

3/ Strictly speaking, these curves have a different loading time: 20 years in Case I, 10 years in Case II and 5 years in Case III. Cases II and III may be thought of, however, as "exaggerated" examples of load curves rapidly rising in the early years and flattening out later, so that they also get fully loaded after 20 years.

4/ This does not mean that both are equally good hydro investments. If the rate of interest is, say, 8% the cost advantage of hydro over thermal is much larger in Case II than in Case IIa, as may be verified by comparing the figures shown at the bottom of Table 7. This simply reflects that, in that case, a return of 10% as of now is better than the same return as of 10 years later.

32. As seen just above, shortening of the "loading time" of the dam from 20 years (Case I) to 10 years (Case II) raises the return in this case from 8% to 10%. Further shortening of the loading time to 5 years (Case III) raises the return further to about 13¼%. Clearly, the maximum return is reached in the case of instantaneous loading, in year 5, of the dam. In that case additional investment in the hydro alternative of 1000 + 1000 - 1500 = 500 gives savings in operating costs of 100 per annum "forever after",[1] i.e., a return of (nearly) 20%. These results are presented graphically in Chart 3 (see Curve A: original data) which is suggestive of the relationship existing between the loading time (with roughly straight-line load growth) and the return on the investment in hydro power. The impact on the return of a year's delay in reaching the full capacity of the dam becomes less the longer it takes. At the level of a loading time of 5 years one year sooner or later is equivalent, in this example, to a difference in the return of the order of one per cent. But around a 10 year loading time it takes a delay of roughly 2 years, and at a level of 15 years a delay of some 4 years, to have a similar effect. This would seem to suggest that small differences in rates of growth, both of which result in the dam reaching full capacity beyond, say, 10 years, are not very important. The return appears not to be very sensitive to such differences in the load growth. Much more importance, of course, attaches to what happens in the early years.

Effect of different cost data

33. The particular result obtained here depends, of course, on the cost data used in this example. With different cost data for the dam, hydro units, thermal plants, and/or additional operating cost of thermal plant, the return on hydro investment - and the sensitivity of the return to changes in loading time - will be different. For example, if the dam costs are raised by nearly 40%, the maximum return, at instantaneous loading, drops sharply from 20% to 12%. But a 10 year loading period gives then a return of nearly 8% (as compared with 10% before) and a 20 year loading period gives a return of about 6% (as compared with 8% before). This is illustrated by Curve C in Chart 3, which also shows the returns obtaining at different loading times if dam costs are raised by nearly 20% (Curve B) and by nearly 60% (Curve D).[2] These results suggest that investments in hydro alternatives with lower maximum ("instantaneous loading") returns are much less sensitive to delays in fully loading the dam capacity, but that the difference is small for loading times beyond 10 years.

34. A further check was made of the influence of different proportions of the four major categories of costs distinguished here on the return on hydro investment for different loading times. Obviously, an "instantaneous loading" return of, for example, 20% as yielded by our basic data, could also be obtained if an increase in the cost of the dam by, say, nearly 40% were offset by an increase in cost of thermal plant (by about 25% per unit), or in additional operating cost of the thermal development (by about 75% per MW). Perhaps more surprisingly, the shape of the curves showing, for

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[1] Neglecting the replacement cost of thermal plants in year 35.

[2] The present worth of costs at various discount rates are given for Cases I, II and III in Table 8.

these changed cost data, the relationship between the rate of return on additional hydro investment and the length of the loading time[1] is not very different from those shown in Chart 3. If the increase in dam costs is offset by higher costs of thermal plant, so as to yield the same instantaneous loading return, returns for longer loading times tend to be somewhat lower than before; if offset by higher additional operating cost of thermal development, returns for longer loading time tend to be somewhat higher than before.[2] Both differences are small, however, - amounting to very roughly some one-half of one per cent from the original rate of return - and the three curves run roughly parallel from year 5 onward, at least over the relevant range of years.[3] This suggests that the instantaneous loading rate of return - which can always speedily be calculated - gives a useful indicating of the return for longer loading times. Thus it becomes possible to see how critical the demand projection is for the outcome of the return calculation.

Curvilinear growth of load

35. The load curves considered so far have one feature in common: they all show growth in constant straight-line fashion from the time of completion of the dam - over the relevant range until the dam is fully loaded.[4] Some impression of the return on additional hydro investment with load curves having "curvilinear" expansion paths may be obtained by inspection. It is obvious, for example, that growth of the load intermediate between the cases represented in Chart 2 will result in an "intermediate" return on the additional investment in hydro. The results of some experiments along these lines are shown in Chart 4. Thin lines represent the previous Cases, I, II, IIa and III, with their respective rates of return (based on the original cost data of Table 7) written in along side. Cases IIb and IIIa, intermediate between II and III, have a return of about 11$\frac{1}{4}$% and 11$\frac{3}{4}$% respectively, as compared with 10% for Case II and 13$\frac{1}{4}$% for Case III.[5] It should be noted that the return in Case IIIa is higher than in Case IIb, although its "loading time" is longer - 10 years rather than 5 years; this is outweighed by the higher load in the early years.

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[1] It should be remembered that the whole argument here is based on "straight-line" growth of the load.

[2] The explanation seems to be the following: longer loading time tends to lower costs, in terms of present worth, because costs are delayed, but to raise them because the discount rate (internal return) becomes lower. On balance, this lowers cost of thermal plant, in terms of present worth, and raises the additional operating cost of thermal development; cf. Table 9. For "fuel", the "discount rate" effect outweighs the "delay effect", as the bulk of the cost occurs in later years. Thus an increase in cost of thermal plant, sufficient to compensate "instantaneously" an increase in dam costs, falls short if the loading time is longer - so that the return on hydro is relatively lower than on the original data. And vice versa for additional operating cost of thermal development.

[3] The relevant data on present worth of costs, varied as indicated, are summarized in Table 9.

[4] This applies also to Case IIa with the proviso that the starting point of its growth is delayed by 10 years, after completion of the dam.

[5] The basic data for Cases IIb and IIIa and other curvilinear cases referred to below, are given in Table 10.

36. A somewhat more difficult exercise perhaps, is the attempt to guess the return on additional hydro investment in cases which "cross over" the straight-line growth cases. Cases IVa and IVb have rapid initial growth of the load, and small increases thereafter, so as to reach full capacity only after 20 years. Once again, the importance of the early years stands out. Case IVa has about the same return as Case II, and Case IVb roughly the same return as Case III, although the respective loading times of Cases IVa and IVb are much longer. Inversely, the influence of slow initial growth of the load and rapid increases later, can be seen by comparing them with benchmarks of the return on additional hydro investment in extreme cases of "delayed instantaneous loading" - shown along the horizontal axis of Chart 4. It is apparent that rapid increases in the load after, say, 10 years, have only a marginal effect on the return.

D. Summary and Conclusions

37. This paper has demonstrated a systematic and logically correct method for comparing the economic merits of alternative power developments. It has shown how the different cost streams involved can be compared by discounting them to obtain their present values, and it has indicated the critical nature of the discount rate used. It has noted that the discount (interest) rate which makes the present values of two alternative cost streams equal is a measure of the return on the additional investment in one (hydro) resulting from the savings in operating costs (over those of the alternative thermal system) for the life of the project. It has shown how to appraise the sensitivity of this return to changes in key data of costs and demand. In particular, it has illustrated a convenient way of assessing the impact of changes in individual cost items on the return by breaking down the usual discounted cash flow calculations by cost components and periods. In this way the sensitivity of return calculations to different estimates of input requirements or input prices can readily be seen and the crucial cost variables can be identified.

38. While variations in the estimated value of inputs - dam, generating, equipment, fuel, labor, etc. - can be made in the cost streams of alternative power developments without changing the timing and capacity of the projected investments, this is not the case with variations in the estimated growth of the market. A more rapid expansion of the market will tend to favor a hydro over a thermal development but the actual effect of a given increase in the growth of demand can only be determined by working out the consequences in terms of a changed pattern of investment. Because the market is a very important and often uncertain element in the appraisal and because the effect of changes in market estimates are not readily evident, it would be most desirable to be able to approximate the effect of such changes on the return calculations in advance - again, in order to identify their importance before devoting effort to the often laborious task of replanning the development of the system.

39. An attempt to work out some rough rules of thumb for this purpose has been made in this paper. This has been done through the use of simplified examples of hydro-thermal comparisons assuming the hydro facilities (the dam) are loaded to capacity over different periods of time. The maximum

rate of return is obtained, of course, on the extreme and convenient assumption that the load grows fast enough to make possible the full utilization of the dam's capacity immediately on its completion. Tentatively it emerges from the analysis that this maximum rate is a good benchmark from which to estimate the lower returns obtained with slower rates of growth. For simple straight-line growth curves the return drops fairly rapidly and regularly from this maximum rate as the period required for full loading is extended. After 10 years the effect on the return of delays of a year rapidly becomes negligible. Different cost structures appear to have only a small influence on these relationships between the rate of return and the loading time. In the case of less simple load-growth curves it is much more difficult to generalize, but the examples presented give some idea of what may be expected.

Table 1.

Cash Flow of Costs - Hydro Development - Lower Load

(in Thousands)

Year	Investments						Operating expenses				
	Dam	hydro units	transmission 400 KV	transmission 230 KV	transmission 115 KV	thermal plant	production plant a)	fuel	transmission	frequency conversion	Total
1961											
1962	11,750						16,440	9,959			
1963	23,600			14,000	2,000		16,440	11,086		30,000	
1964	106,200			25,000	2,000		16,440	11,763		30,000	
1965	147,500			38,000	2,000		16,440	13,695		30,000	
1966	74,900	51,100					14,620	9,296	830		
1967	43,300	57,200		12,900			14,620	10,704	830		
1968			38,700				14,620	13,624	959		
1969		51,100	51,500				16,220	3,532	959		
1970		57,200	52,300				16,220	7,540	959		
1971							16,520	2,052	2,384		
1972		51,100					16,520	2,052	2,384		
1973		57,200					16,520	2,052	2,384		
1974		-					17,520	2,052	2,384		
1975		51,100					17,520	2,052	2,384		
1976		57,200					17,520	2,052	2,384		
1977		-					18,620	2,052	2,384		
1978		51,100					18,620	2,052	2,384		
1979		57,200					18,620	2,052	2,384		
1980		-					19,320	2,052	2,384		
(1981)							19,320	2,052	2,384		
..											
1983						90,000	↑	↑	↑		
..							|	|	|		
1985						180,000	|	|	|		
..							|	|	|		
1995				77,000	6,000		|	|	|		
..							|	|	|		
1997				12,900			|	|	|		
..							|	|	|		
2000			142,500				|	|	|		
..							|	|	|		
2013						90,000	|	|	|		
..							|	|	|		
2015						180,000	|	|	|		
..							|	|	|		
2025				77,000	6,000		|	|	|		
..							|	|	|		
2027				12,900			↓	↓	↓		
2028							19,320	2,052	2,384		
Present worth in 1962 (PW) of costs in period:											
1962-1980)	330,580	265,123	85,443	74,231	5,201	0	176,168	78,973	12,112	78,016	1,105,847
1981-2028)at 7½%	0	0	9,126	9,032	615	59,966	63,165	6,709	7,794	0	156,407
Total 1962-2028)	330,580	265,123	94,569	83,263	5,816	59,966	239,333	85,682	19,906	78,016	1,262,254
1962-1980)	322,035	243,575	80,046	72,469	5,108	0	165,105	75,999	10,924	76,621	1,051,882
1981-2028)at 8½%	0	0	6,419	6,473	442	47,582	47,279	5,022	5,834	0	119,051
Total 1962-2028)	322,035	243,575	86,465	78,942	5,550	47,582	212,384	81,021	16,758	76,621	1,170,933

a) Operating and maintenance expenses of both hydro and thermal plant.

N.B. The cash flow of costs does not include any transactions that are merely financial or accounting such **as depreciation, amortization and interest. It includes only** expenditures on goods and services in the year in which they are made. The hydro development results in a system using not only hydro but also some thermal plants.

Thermal development
Lower load

Table 7.

Cash Flow of Costs - Thermal Development - Lower Load

(in Thousands)

Year	Dam	hydro units	Investments transmission 400 KV	transmission 230 KV	transmission 115 KV	thermal plant	Operating expenses production plant	fuel	transmission	frequency conversion	Total
1961											
1962							16,440	9,959			
1963				14,000	2,000		16,440	11,086		30,000	
1964				25,000	2,000		16,440	11,763		30,000	
1965				38,000	2,000		16,440	13,695		30,000	
1966						29,000	14,620	9,296	830		
1967						59,000	14,620	10,704	830		
1968						59,000	16,180	12,273	830		
1969						59,000	17,740	13,382	830		
1970						30,000	19,300	16,255	830		
1971						29,000	20,860	17,895	830		
1972						30,000	20,860	19,363	830		
1973						29,000	22,420	19,836	830		
1974						59,000	22,420	21,308	830		
1975						59,000	23,980	25,434	830		
1976						30,000	25,540	29,718	830		
1977						29,000	27,100	31,542	830		
1978						88,000	27,100	34,062	830		
1979						89,000	28,660	39,904	830		
1980						30,000	31,780	42,791	830		
(1981)							33,340	54,631	830		
..											
1983						90,000	↑	↑	↑		
..											
1985						180,000					
..											
1995				77,000	6,000						
..											
1998						90,000					
..											
2000						90,000					
..											
2002						90,000					
..											
2004						90,000					
..											
2006						90,000					
..											
2008						90,000					
..											
2010						180,000					
..											
2013						90,000					
..											
2015						180,000					
..											
2025				77,000	6,000						
..											
2028							33,340	54,631	830		
Present worth in 1962 (PW) of costs in period:											
1962-1980) at 7½%	0	0	0	65,245	5,201	326,567	206,207	183,062	5,898	78,016	870,196
1981-2028)	0	0	0	7,888	615	94,255	109,002	178,611	2,714	0	393,085
Total 1962-2028)	0	0	0	73,133	5,816	420,822	315,209	361,673	8,612	78,016	1,263,281
1962-1980)	0	0	0	63,890	5,108	296,348	191,739	168,133	5,396	76,621	807,235
1981-2028) at 8½%	0	0	0	5,667	442	70,961	81,589	133,691	2,031	0	294,381
Total 1962-2028)	0	0	0	69,557	5,550	367,309	273,328	301,824	7,427	76,621	1,101,616

N.B. The cash flow of costs does not include any transactions that are merely financial or accounting such as depreciation, amortization and interest. It includes only expenditures on goods and services in the year in which they are made.

Table 3.

Cash Flow of Costs - Hydro Development - Higher Load

(in Thousands)

	Investment						Operating expenses				
Year	Dam	hydro units	transmission 400 KV	transmission 230 KV	transmission 115 KV	thermal plant	production plant a)	fuel	transmission	frequency conversion	Total
1961											
1962	11,750										
1963	23,600			14,000	2,000		16,440	10,007		30,000	
1964	106,200			25,000	2,000		16,440	11,178		30,000	
1965	147,500			38,000	2,000		16,440	11,859		30,000	
1966	74,900	51,100					16,440	13,719			
1967	43,300	57,200		12,900			16,440	11,730	830		
1968	-		38,700				16,440	13,588	830		
1969	-	51,100	51,500				14,260	14,784	959		
1970	-	57,200	52,300				16,220	4,740	959		
1971	-						16,220	8,304	959		
1972		51,100					16,520	2,052	2,384		
1973		57,200					16,520	2,052	2,384		
1974		51,100					16,520	3,572	2,384		
1975		57,200					17,520	2,052	2,384		
1976		51,100					17,520	2,052	2,384		
1977		57,200					18,620	2,052	2,384		
1978							18,620	2,052	2,384		
1979							19,320	2,052	2,384		
1980							19,320	2,052	2,384		
(1981)							↑	↑	↑		
..											
1983						90,000					
..											
1985						180,000					
..											
1995				77,000	6,000						
..											
1997				12,900							
..											
2000			142,500								
..											
2013						90,000					
..											
2015						180,000					
..											
2025				77,000	6,000						
..											
2027				12,900			↓	↓	↓		
2028							19,320	2,052	2,384		
Present worth in 1962 (PW) of costs in period:											
1962-1978)	330,580	273,282	85,443	74,231	5,201	0	168,490	84,476	10,766	78,016	1,110,485
1979-1980) at 7½%	0	0	0	0	c	0	10,906	1,158	1,346	0	13,410
1981-2028)	0	0	9,126	9,032	615	59,966	63,165	6,709	7,794	0	156,407
Total 1962-2028)	330,580	273,282	94,569	83,263	5,816	59,966	242,561	92,343	19,906	78,016	1,280,302
1962-1978)	322,035	251,618	80,046	72,469	5,108	0	158,847	81,332	9,780	76,621	1,057,856
1979-1980) at 8½%	0	0	0	0	0	0	9,276	985	1,145	0	11,406
1981-2028)	0	0	6,419	6,473	442	47,582	47,279	5,022	5,834	0	119,051
Total 1962-2028)	322,035	251,618	86,465	78,942	5,550	47,582	215,402	87,339	16,759	76,621	1,188,313

a) Operating and maintenance expenses of both hydro and thermal plants.

N.B. The cash flow of costs does not include any transactions that are merely financial or accounting such as depreciation, amortization and interest. It includes only expenditures on goods and services in the year in which they are made. The hydro development results in a system using not only hydro but also some thermal plants.

Thermal development
Higher load

Table 4.

Cash Flow of Costs - Thermal Development - Higher Load

(in Thousands)

	Investment						Operating expenses				
Year	Dam	hydro units	transmission 400 KV	transmission 230 KV	transmission 115 KV	thermal plant	production plant	fuel	transmission	frequency conversion	Total
1961											
1962											
1963							16,440	10,007			
1964				14,000	2,000		16,440	11,178		30,000	
1965				25,000	2,000		16,440	11,859		30,000	
1966				38,000	2,000		16,440	13,719		30,000	
1967						29,000	14,620	11,068	830		
1968						59,000	14,620	12,832	830		
1969						59,000	16,180	13,649	830		
1970						59,000	17,740	14,590	830		
1971						30,000	19,300	17,019	830		
1972						29,000	20,860	19,239	830		
1973						59,000	20,860	21,279	830		
1974						59,000	22,420	22,592	830		
1975						59,000	23,980	23,685	830		
1976						59,000	25,540	26,937	830		
1977						88,000	27,100	34,490	830		
1978						89,000	28,660	40,143	830		
1979						30,000	31,780	45,667	830		
1980							33,340	52,875	830		
(1981)							↑	52,875	↑		
..								61,532			
1983						90,000		↑			
..											
1985						180,000					
..											
1995				77,000	6,000						
..											
1999						270,000					
..											
2004						180,000					
..											
2007						270,000					
..											
2013						90,000					
..											
2015						180,000					
..											
2025				77,000	6,000		↓	↓			
2028							33,340	61,532	830		
Present worth in 1962 (PW) of costs in period:											
1962-1978)				65,245	5,201	343,104	193,009	175,357	5,429	78,016	865,361
1979-1980) at 7½%	0	0	0	0	0	0	18,820	29,848	469	0	49,137
1981-2028)	0	0	0	7,888	615	97,610	109,002	201,173	2,714	0	419,002
Total 1962-2028)	0	0	0	73,133	5,816	440,714	320,831	406,378	8,612	78,016	1,333,500
1962-1978)	0	0	0	63,890	5,108	314,332	180,612	164,388	4,998	76,621	809,949
1979-1980) at 8½%	0	0	0	0	0	0	16,008	25,388	398	0	41,794
1981-2028)	0	0	0	5,667	442	73,501	81,589	150,579	2,031	0	313,809
Total 1962-2028)	0	0	0	69,557	5,550	387,833	278,209	340,355	7,427	76,621	1,165,552

N.B. The cash flow of costs does not include any transactions that are merely financial or accounting such as depreciation, amortization and interest. It includes only expenditures on goods and services in the year in which they are made.

Table 5.

Summary of Present Worth of Costs (Lower Load Development)

(in thousands of Thousands)

Cost Component	Period 1962-2028			Period 1962-1980			Period 1981-2028		
	hydro dev.	thermal dev.	Difference	hydro dev.	thermal dev.	Difference	hydro dev.	thermal dev.	Difference
				(Present worth at 7½ per cent)					
Dam	331	-	331	331	-	331	-	-	-
Hydro units	265	-	265	265	-	265	-	-	-
Transmission 400 KV	95	-	95	85	-	85	10	-	10
Transmission 230 KV	83	73	10	74	65	9	9	8	1
Transmission 115 KV	6	6	-	5	5	-	1	1	-
Thermal plant	60	421	-361	-	327	-327	60	94	-34
Operating cost production plant	239	315	- 76	176	206	- 30	63	109	-46
Fuel	86	362	-276	79	183	-104	7	179	-172
Operating cost transmission	20	9	11	12	6	6	8	3	5
Frequency conversion	78	78	-	78	78	-	-	-	-
Total	1262	1263	-1	1106	870	236	156	393	-237
				(Present worth at 8½ per cent)					
Dam	322	-	322	322	-	322	-	-	-
Hydro units	244	-	244	244	-	244	-	-	-
Transmission 400 KV	86	-	86	80	-	80	6	-	6
Transmission 230 KV	79	70	9	72	64	8	7	6	1
Transmission 115 KV	6	6	-	5	5	-	1	1	-
Thermal plant	48	367	-319	-	296	-296	48	71	-23
Operating cost production plant	212	273	- 61	165	192	- 27	47	81	-34
Fuel	81	302	-221	76	168	- 92	5	134	-129
Operating cost transmission	17	7	10	11	5	6	6	2	4
Frequency conversion	77	77	-	77	77	-	-	-	-
Total	1171	1102	69	1052	807	245	119	295	-176

N.B. For basic data see Tables 1 and 2.

Lower Load
Higher Load

Table 6.

Present Worth of Costs: Comparison of Higher and Lower Load Development, 1962 - 2028

(in thousands of Thousands)

	Hydro development			Thermal development			Difference (hydro - thermal)		
	Lower load (1)	Higher load (2)	Difference (2) - (1)	Lower load (1)	Higher load (2)	Difference (2) - (1)	Lower load (1)	Higher load (2)	Difference (2) - (1)
				(present worth at 7½ per cent)					
Cost Component									
Dam	331	331	-	-	-	-	331	331	-
Hydro units	265	273	8	-	-	-	265	273	8
Transmission 400 KV	95	95	-	-	-	-	95	95	-
Transmission 230 KV	83	83	-	73	73	-	10	10	-
Transmission 115 KV	6	6	-	6	6	-	-	-	-
Thermal plant	60	60	-	421	441	20	-361	-381	-20
Operating cost production plant	239	243	4	315	321	6	- 76	- 78	- 2
Fuel	86	92	6	362	406	44	-276	-314	-38
Operating cost transmission	20	20	-	9	9	-	11	11	-
Frequency conversion	78	78	-	78	78	-	-	-	-
Total	1262	1280	18	1263	1334	71	-1	54	-53
				(present worth at 8½ per cent)					
Dam	322	322	-	-	-	-	322	322	-
Hydro units	244	252	8	-	-	-	244	252	8
Transmission 400 KV	86	86	-	-	-	-	86	86	-
Transmission 230 KV	79	79	-	70	70	-	9	9	-
Transmission 115 KV	6	6	-	6	6	-	-	-	-
Thermal plant	48	48	-	367	388	21	-319	-340	-21
Operating cost production plant	212	215	3	273	278	5	- 61	- 63	- 2
Fuel	81	87	6	302	340	38	-221	-253	-32
Operating cost transmission	17	17	-	7	7	-	10	10	-
Frequency conversion	77	77	-	77	77	-	-	-	-
Total	1170	1188	18	1102	1166	64	69	22	-46

N.B. For basic data see Tables 1, 2, 3 and 4.

Table 7a

Different patterns of growth of load: simplified cash flows of alternative hydro and thermal investments

	Case I (Ia and Ib)					Case II				
	load	cost				load	cost			
Year	MW	dam	hydro units	thermal units	additional operating cost of thermal development	MW	dam	hydro units	thermal units	additional operating cost of thermal development
0	500					500				
1	600					600				
2	700					700				
3	800					800				
4	900					900				
5	1000	1000	100	150		1000	1000	100	150	
6	1075				5	1150		100	150	10
7	1150		100	150	10	1300		100	150	20
8	1225				15	1450		100	150	30
9	1300		100	150	20	1600		100	150	40
10	1375				25	1750		100	150	50
11	1450		100	150	30	1900		100	150	60
12	1525				35	2050		100	150	70
13	1600		100	150	40	2200		100	150	80
14	1675				45	2350		100	150	90
15	1750		100	150	50	2500				100
16	1825				55	↕				↕
17	1800		100	150	60					
18	1875				65					
19	2050		100	150	70					
20	2125				75					
21	2200		100	150	80					
22	2275				85					
23	2350		100	150	90					
24	2425				95					
25	2500				100					
26	↕				↕					
↕			year 35 ↕ 53	a) 150 ↕ 150				year 35 ↕ 44	a) 150 ↕ 150	
65	2500				100	2500				100
Present worth in year 5 (PW) of costs in years:										
5-15)		1000	423	634	163		1000	725	1087	327
16-25) at 8%		0	128	192	231		0	0	0	311
26-65)		0	0	82	256		0	0	108	256
Total 5-65)		1000	551	908	650		1000	725	1195	894
Internal rate of return on additional hydro investment:			8 per cent					10 per cent		

---

a) replacement investments

Assumptions:

1 thermal unit = 1 hydro unit = 150 MW
Total capacity dam: 10 units = 1500 MW
Life: thermal unit - 30 years
hydro unit - 60 years
dam - more than 60 years

costs:	
dam:	1000
1 hydro unit:	100
1 thermal unit:	150
add. oper. cost (incl. fuel) of thermal dev.:	1/15 per MW

Table 7b

Different patterns of growth of load: simplified cash flows of alternative hydro and thermal investments

	Case IIa					Case III				
	load	cost				load	cost			
Year	MW	dam	hydro units	thermal units	additional operating cost of thermal development	MW	dam	hydro units	thermal units	additional operating cost of thermal development
0	500					500				
1	600					600				
2	700					700				
3	800					800				
4	900					900				
5	1000	[1000] x)				1000	1000	200	300	
6					68.3	1300		200	300	20
7					70.0	1600		200	300	40
8					71.7	1900		200	300	60
9					73.3	2200		200	300	80
10					75.0	2500		-	-	100
11					76.7	↑		-	-	↑
12					78.3					
13					80.0					
14					81.7					
15	1000	[1000] y)	100	150	83.3					
16	1150		100	150	85.0					
17	1300		100	150	86.7					
18	1450		100	150	88.3					
19	1600		100	150	90.0					
20	1750		100	150	91.7					
21	1900		100	150	93.3					
22	2050		100	150	95.0					
23	2200		100	150	96.7					
24	2350		100	150	98.3					
25	2500		-	-	100					
26	↑				↑					
year a) 35									300	
39									300	
year a) 45				150						
54				150						
65	2500				100	2500				100

Present worth in year 5 (PW) of costs in years:									
5-15)	at 8%	463	46	69	0	1000	862	1293	489
16-25)		0	289	434	151	0	0	0	311
26-65)		0	0	50	256	0	0	129	256
Total 5-65)		463	335	553	407	1000	862	1422	1056

Internal rate of return on additional hydro investment:	6 per cent (x) or 10 per cent (y)	13¼ per cent

---

a) replacement investments

Assumptions:

1 thermal unit = 1 hydro unit = 150 MW
Total capacity dam: 10 units = 1500 MW
Life: thermal unit - 30 years
hydro unit - 60 years
dam - more than 60 years

costs:	
dam:	1000
1 hydro unit:	100
1 thermal unit:	150
add. oper. cost (incl. fuel) of thermal dev.:	1/15 per MW

Table 8

Present worth of costs of hydro/thermal alternatives for different loading times

Cost Component \ Present Worth at	14%	12%	11%	10%	9%	8%	7%	6%	5%
Case I									
Dam)						1000 a)	1000 a)	1000 a)	1000 a)
Hydro units)						551	586	625	672
Thermal units)						908	973	1100	1241
Add. oper. cost) of thermal dev.)						650	730	907	1141
Case II									
Dam)				1000 a)	1000 a)	1000 a)			
Hydro units)				676	700	725			
Thermal units)				1072	1129	1195			
Add. oper. cost) of thermal dev.)				612	708	894			
Case III									
Dam)	1000 a)	1000 a)	1000 a)		1000 a)	1000 a)			
Hydro units)	782	807	820		848	862			
Thermal units)	1196	1250	1283		1367	1422			
Add. oper. cost) of thermal dev.)	559	615	685		871	1056			

a) Or the higher dam costs used in deriving Curves B-D in Chart 3.

Note: Cases I, II, and III refer to "straight line" loading times of 20, 10 and 5 years respectively. Cf. Chart 2 and Table 7. Basic cost data as in para. 29, and Table 7. Dam costs may be varied, as discussed in para. 26; the resulting effect on the rate of return emerges from the table. For example, with dam costs at 1000 the rate of return, in Case I, is 8 per cent (100 + 551 = 908 + 650 approx.). With dam costs nearly 40 per cent higher, at 1383, the return falls to 6 per cent (1383 + 625 = 1100 + 907 approx.)

Table 9

Influence of different proportions of basic costs on relation between rate of return and loading time

Cost data / Components	Original cost data	Modified cost data a)	Modified cost data b)
		Instantaneous loading (PW at 20 per cent)	
Dam)	1000	1383	1383
Hydro units)	1000	1000	1000
Thermal units)	1507	1883	1507
Add. oper. cost) of thermal dev.)	500	500	875
rate of return	20%	20%	20%
		Case I (PW at 8 per cent)	
Dam)	1000	1383	1383
Hydro units)	551	551	551
Thermal units)	908	1135	908
Add. oper. cost) of thermal dev.)	650	650	1135
rate of return	8%	c. 7¼%	c. 8½%
		Case II (PW at 10 per cent)	
Dam)	1000	1383	1383
Hydro units)	676	676	676
Thermal units)	1072	1340	1072
Add. oper. cost) of thermal dev.)	612	612	1071
rate of return	10%	c. 9½%	c.10½%
		Case III (PW at 14 per cent)	
Dam)	1000	1383	1383
Hydro units)	782	782	782
Thermal units)	1196	1495	1196
Add. oper. cost) of thermal dev.)	559	559	980
rate of return	13¼%	c.12¾%	c. 14%

a) dam cost, plus 38 per cent; thermal unit cost, plus 25 per cent
b) dam cost, plus 38 per cent; additional operating cost of thermal development, plus 75 p.c.

Note: See text, para. 34, for explanation. Cases I, II and III refer to "straight line" loading times of 20, 10 and 5 years respectively. Cf. Chart 2 and Table 7. Present worth data at discount rate approximately "right" for Case considered; the "weight" of cost increases varies with this discount rate.

Table 10a

Some stylized curvilinear patterns of load growth: simplified cash flows of alternative hydro and thermal investments

	Case IIb					Case IIIa				
	load	cost				load	cost			
Year	MW	dam	hydro units	thermal units	additional operating cost of thermal development	MW	dam	hydro units	thermal units	additional operating cost of thermal development
0	500					500				
1	600					600				
2	700					700				
3	800					800				
4	900					900				
5	1000	1000	100	150		1000	1000	200	300	
6	1150		100	150	10	1300		200	300	20
7	1300		100	150	20	1600		200	300	40
8	1450		100	150	30	1800				53.3
9	1600		600	900	40	1900		100	150	60
10	2500				100	2000		100	150	66.6
11	↑				↑	2100				73.3
12						2200		100	150	80
13						2300		100	150	86.6
14						2400				93.3
15						2500				100
16						↑				↑
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
↑										
↓	↓				↓	↓				↓
65	2500				100	2500				100

Case IIb:

year[a]	
35	150
36	150
37	150
38	150
39	900

Case IIIa:

year[a]	
35	300
36	300
37	300
..	
39	150
40	150
..	
42	150
43	150

Internal rate of return on additional hydro investment:	$11\frac{1}{4}$ per cent	$11\frac{3}{4}$ per cent

---

a) replacement investments

Assumptions:

1 thermal unit = 1 hydro unit = 150 MW
Total capacity dam: 10 units = 1500 MW
Life: thermal unit - 30 years
hydro unit - 60 years
dam - more than 50 years

costs:	
dam:	1000
1 hydro unit:	100
1 thermal unit:	150
add. oper. cost (incl. fuel) of thermal dev.:	1/15 per MW

Table 10b

Some stylised curvilinear patterns of load growth: simplified cash flows of alternative hydro and thermal investments

	Case IVa					Case IVb				
	load	cost				load	cost			
Year	MW	dam	hydro units	thermal units	additional operating cost of thermal development	MW	dam	hydro units	thermal units	additional operating cost of thermal development
0	500					500				
1	600					600				
2	700					700				
3	800					800				
4	900					900				
5	1000	1000	400	600		1000	1000	100	1050	
6	1550				36.6	2025				68.3
7	1600		100	150	40.0	2050		100	150	70.0
8	1650				43.3	2075				71.7
9	1700				46.6	2100				73.3
10	1750		100	150	50.0	2125				75.0
11	1800				53.3	2150				76.7
12	1850				56.6	2175				78.3
13	1900		100	150	60.0	2200		100	150	80.0
14	1950				63.3	2225				81.7
15	2000				66.6	2250				83.3
16	2050		100	150	70.0	2275				85.0
17	2100				73.3	2300				86.7
18	2150				76.6	2325				88.3
19	2200		100	150	80.0	2350		100	150	90.0
20	2250				83.3	2375				91.7
21	2300				86.6	2400				93.3
22	2350		100	150	90.0	2425				95.0
23	2400				93.3	2450				96.7
24	2450				96.6	2475				98.3
25	2500				100.0	2500				100.0
26 ↑	↑				↑	↑				↑
				year a)					year a)	
				35 600					35 1050	
				37 150					37 150	
				40 150					43 150	
				43 150					49 150	
				46 150						
				49 150						
				52 150						
↓ 65	↓ 2500				↓ 100	↓ 2500				↓ 100

Internal rate of return on additional hydro investment:	10½ per cent	14 per cent

---

a) replacement investments

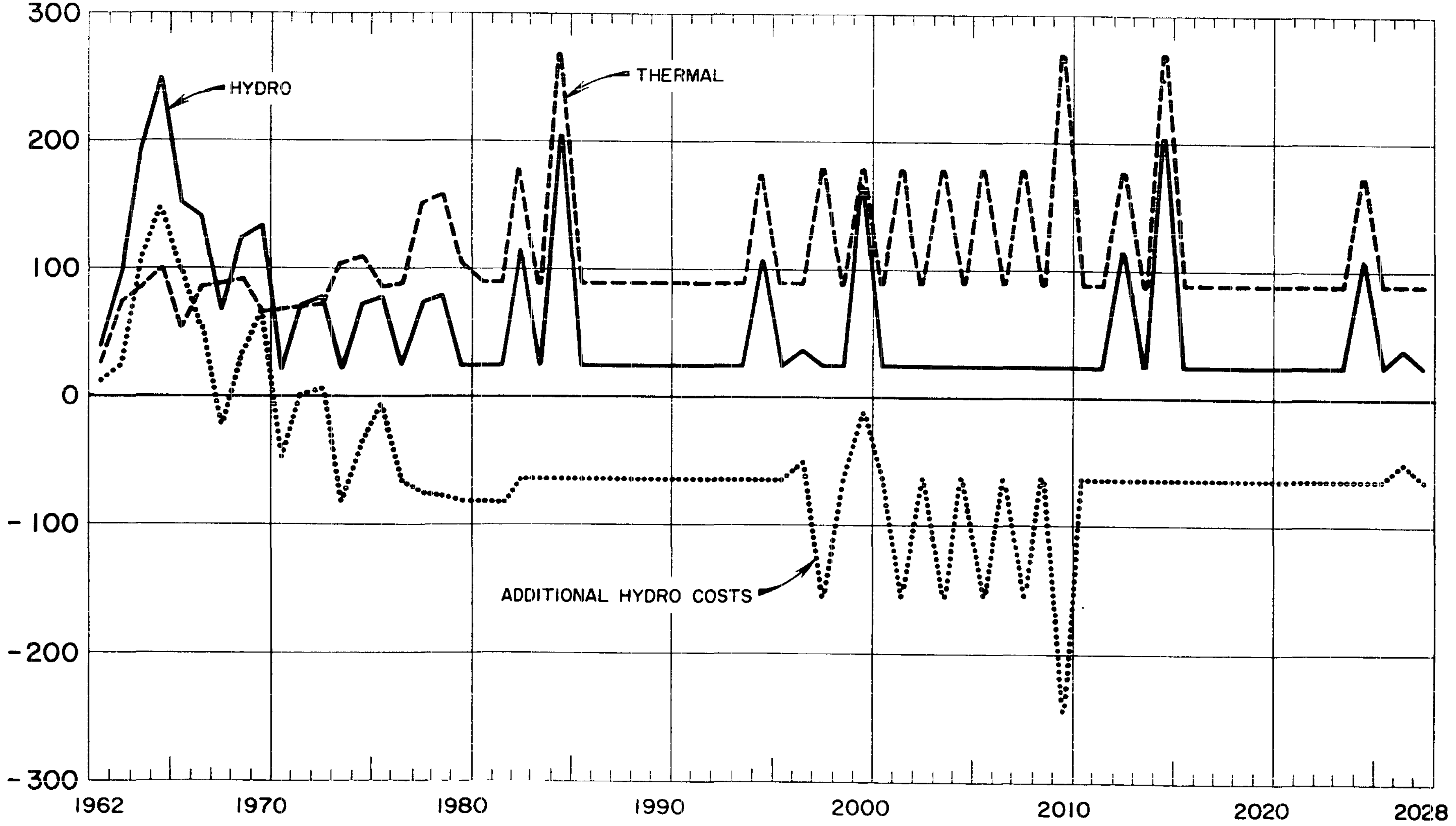
Assumptions:

1 thermal unit = 1 hydro unit = 150 MW
Total capacity dam: 10 units = 1500 MW
Life: thermal unit = 30 years
hydro unit = 60 years
dam – more than 60 years

costs:	
dam:	1000
1 hydro unit:	100
1 thermal unit:	150
add. oper. cost (incl. fuel) of thermal dev.:	1/15 per MW

COMPARISON OF CASH FLOWS OF HYDRO AND THERMAL DEVELOPMENT – LOWER LOAD

(THOUSANDS)



NOTE: For basic data see Tables 1 and 2

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CHART I

ILLUSTRATIVE PATTERNS OF LOAD GROWTH

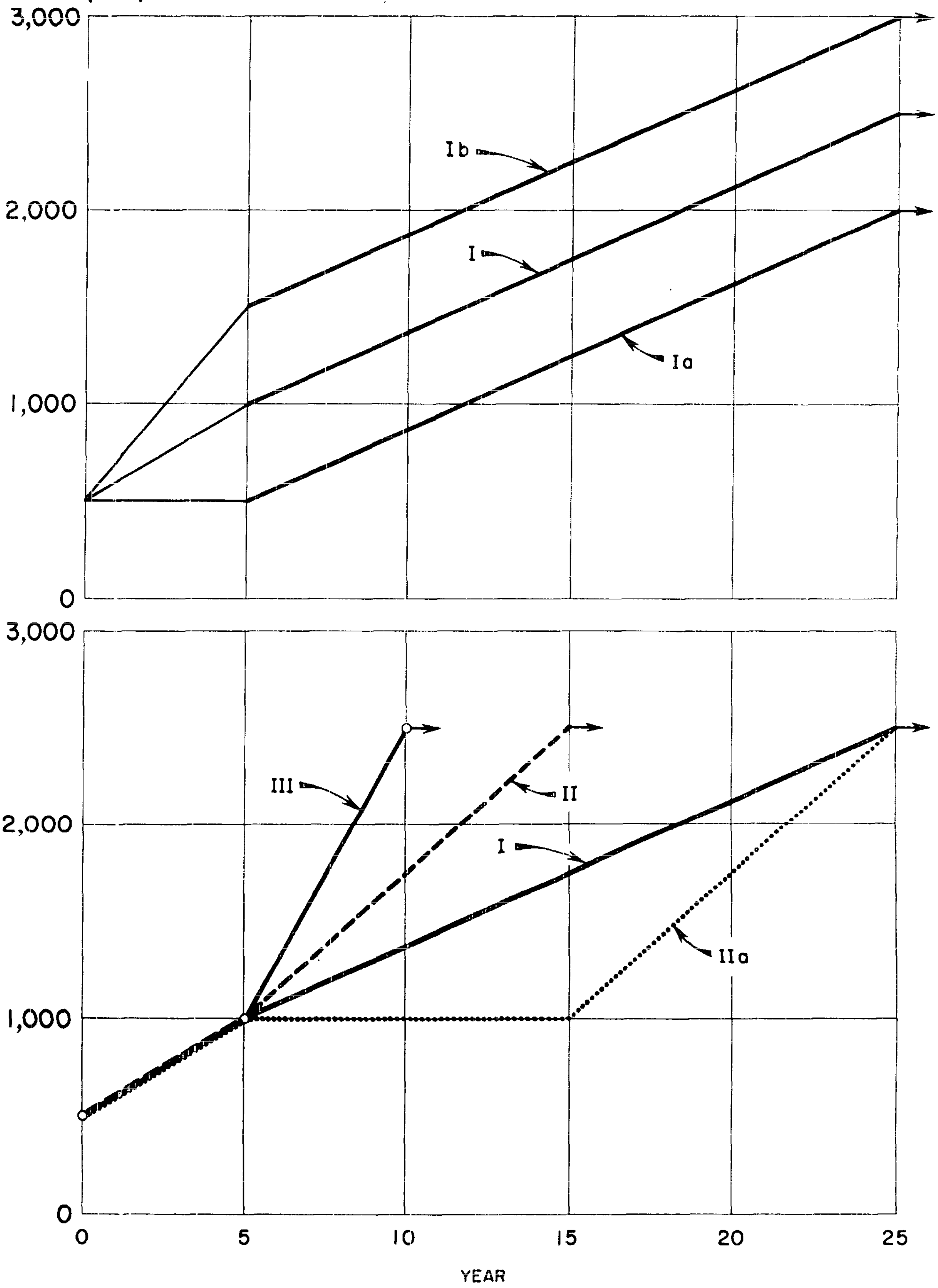

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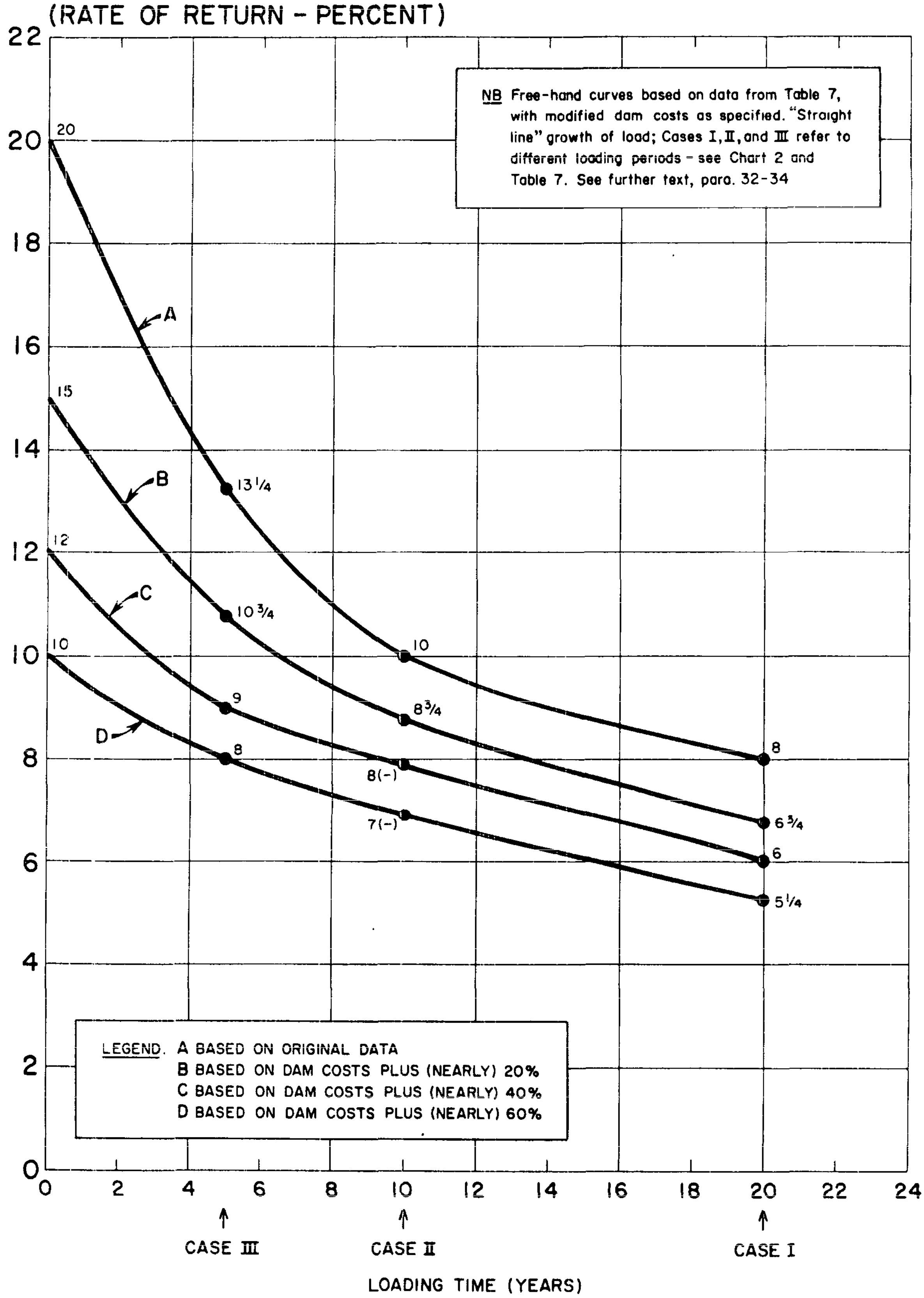
CHART 3

RELATIONSHIP BETWEEN RATE OF RETURN ON INVESTMENT IN HYDRO AND LENGTH OF LOADING TIME OF DAM



NB Free-hand curves based on data from Table 7, with modified dam costs as specified. "Straight line" growth of load; Cases I, II, and III refer to different loading periods - see Chart 2 and Table 7. See further text, para. 32-34

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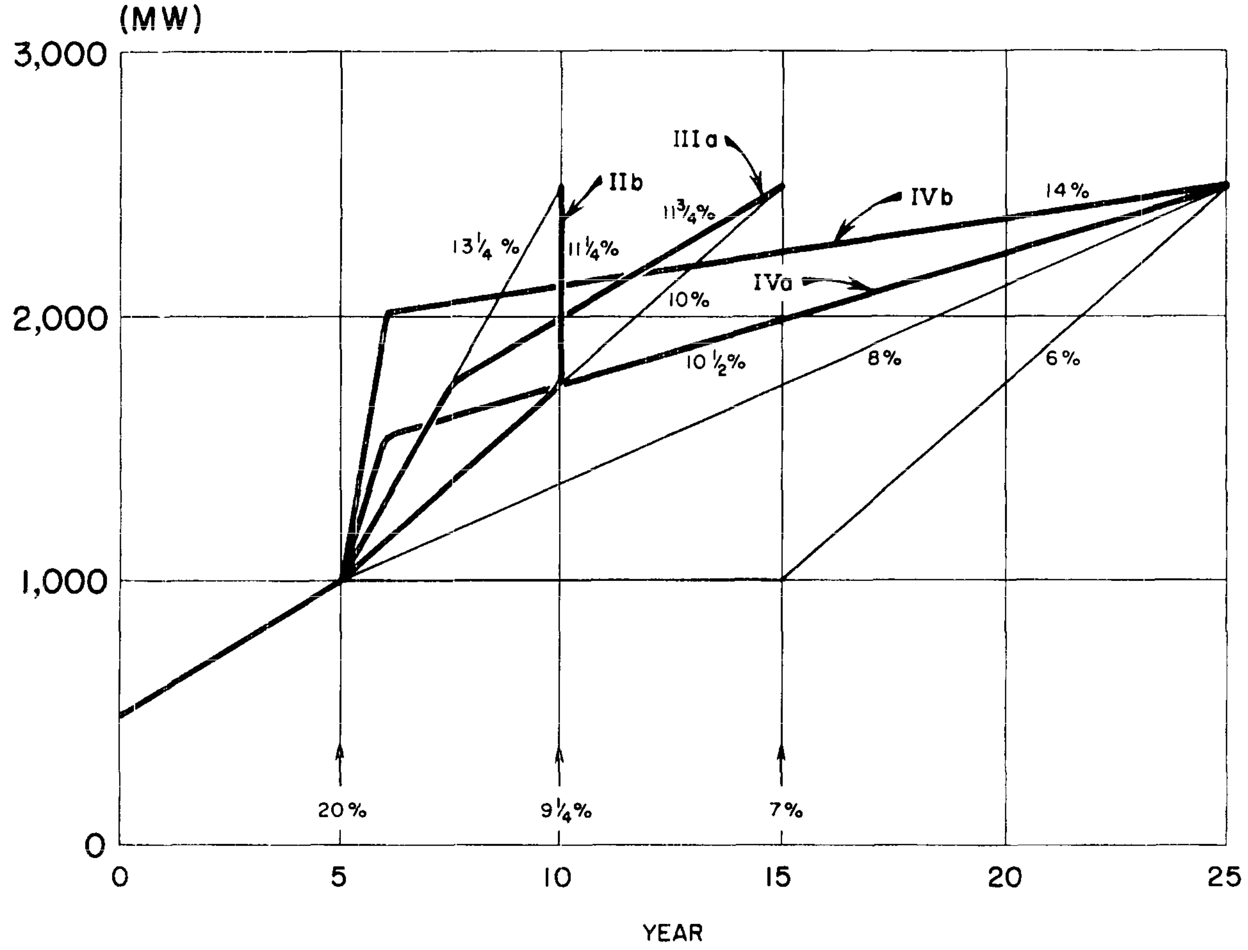
CHART 4

RETURN ON HYDRO INVESTMENT FOR DIFFERENT LOAD GROWTH



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NOTE: Thin lines represent the original Cases I, II, IIa, and III Thick lines represent the new "Curvilinear" Cases IIb, IIIa, IVa, and IVb. Respective rates of return (based on Original Cost data of Table 7) are written in alongside. Rates of return written in along horizontal axis refer to instantaneous loading of dam capacity in year indicated. See futher text, para. 35-36.