PART V

PRACTICAL SYSTEM PLANNING

CHAPTER 15

RULES OF THUMB FOR OPTIMAL PLANNING

It now seems appropriate to ask whether the formal model set up in Part IV might find application in the practical planning of municipal investments in water supply system capacity. It does seem clear that if it is left to each town, or even each engineering firm, to formulate a version of the model and to estimate the applicable parameters on a case-by-case basis, little will be done. On the other hand, it is conceivable that some agency could put together a suitable general model, run it many times while varying the parameters over relevant ranges, and publish in a handbook or similar form a summary of the results.

In order to illustrate this possibility on the basis of the relatively simple model presented here, we have calculated two summary measures which would answer the key questions of the optimal timing and size of capacity increments for given sets of parameter values.[1] Both these measures are based on the already familiar concepts of projected demand (and its rate of growth) and safe yield, for we felt that these are key terms in the existing planning process, and that it would be wise to minimize breaks with present practice.

OPTIMAL TIMING OF CAPACITY INCREMENTS

We first examined the timing question by looking at the ratio of demand to safe yield (the inadequacy level) existing at times $\hat{T}_1$ and $\hat{T}_2$ (the times at which increments were added) for each program run. Those ratios were generally not exactly equal for a particular parameter combination, but

[1] Note that in calculating these measures we must generally use solution values generated for times T_1 and T_2 (increments s_1 and s_2) only, since in time zero and time 60 the model was free to choose only increment size and not timing.

TABLE 44. OPTIMAL INCREMENT TIMING

For $z = 12$

and if ρ =	0.03	0.05	0.07
If y = 0.88	1.11	1.15	1.16
0.78	1.08	1.12	1.15
0.68	1.06	1.12	1.12

For $z = 5.4$

and if ρ =	0.03	0.05	0.07
If y = 0.88	1.24	1.33	1.39
0.78	1.14	1.29	1.34
0.78	*	1.25	1.30

For $z = 4.3$

and if ρ =	0.03	0.05	0.07
If y = 0.88	1.30	1.42	1.58
0.78	1.21	1.36	1.57
0.68	1.18	1.35	*

Notes:

The table entries indicate the safe-yield ratio at which expansion should be undertaken.

No table has been provided for $z = 3.2$ because of the generally lower quality of the computational results achieved in those runs.

* Solutions not reliable.

the differences were almost always small. To illustrate the kind of planning aid we have in mind, we present as Table 44 a sample handbook timing table. Entering the table for the appropriate value of z (depending on stance, climate, etc.) for one's situation, one runs down the left-hand side to the applicable scaling factor (y, depending primarily on terrain and climate), and across this row to the discount rate column describing the cost of capital to the town. The entry gives the adequacy level at which it is optimal to plan to add an increment of safe yield.[2]

The results presented in the table follow a very plausible pattern. For given z, with higher interest rates (greater savings from postponement) and less important economies of scale, it is optimal to let system adequacy fall farther (let D/Y grow larger) before building an addition to capacity. For given interest rate and scaling factor, a lower value of z (indicating less

[2] In fact, except under very special conditions on the relative sizes of the parameters, α, β, and y, the ratio of demand to safe yield at which an increment is added will change over time. This change will nearly always be fairly small (on the order of 5 percent total over 20 years) and so we feel justified in ignoring it.

spectacular growth in expected losses with deteriorating adequacy) also encourages longer postponement of additions to adequacy.

OPTIMAL SIZE OF CAPACITY INCREMENTS

We express our results for increment sizes in terms of years of demand provided for. Specifically, we calculate the ratio of the system safe yield *with* the new increment to that existing before, and determine what period in years is implied by that ratio, where we treat safe yield as though it were growing at the rate α, the rate of growth of total demand. Symbolically, we define the optimal increment size τ at building time T as:

$$\tau = \frac{1}{\alpha} \ln \left[\frac{\bar{S} + s_o + \ldots + s_T}{\bar{S} + s_o + \ldots + s_{T-1}} \right] \tag{15-1}$$

Note that this measure of increment size is in units which we would expect to be independent of the rate of growth of demand, in the sense that whether this rate of growth is high or low, for given z, ρ, and y the optimal increment should cover the same number of years. The physical size of a τ-year increment will depend, of course, on the rate of growth.[3]

We present in Table 45 sample handbook pages for the planning of increment sizes. The method of entering the tables is the same as for Table 44; here the entry tells the manager how big his increment should be in terms of years. To translate into physical size, he uses the formula

$$\Delta S = S\,(\text{existing})\,(e^{\alpha\tau} - 1), \tag{15-2}$$

where τ is the table entry and α is the estimated rate of growth of demand for his system.

The general patterns of the table are, again, in keeping with economic common sense. The lower the interest rate, for given scale factor, the larger the optimal increment size. For given ρ, decreasing the scale factor increases the optimal increment size.[4] Perhaps the most surprising feature is, however, the marked lack of sensitivity of the increment size of z.

[3] That the model actually does give us the same information on optimal increment size was checked by calculations over the several growth rate combinations used in the calculations for Chapter 14. Since these runs were made with constant z, y, and ρ, we hypothesized that for each growth rate the model would build for the same number of years of demand growth. This was, in fact, the case within the limits of error implied by our computational problems.

[4] As with the timing rule, there is a problem introduced because the optimal increment size will, in general, change from time $\overline{T_1}$ to time $\overline{T_2}$. Because of the complexity of the partial derivatives with respect to increment sizes, it is difficult to make any conclusive formal argument showing how the increment sizes should vary from $\hat{s}_1$ to $\hat{s}_2$ for particular parameter values. Examination of the computational results indicates, however, that the problem will be greatest when y and ρ are both relatively large, and that if ρ is small, the problem may be insignificant.

TABLE 45. OPTIMAL INCREMENT SIZE

For z = 12

and if ρ =	0.03	0.05	0.07
If y = 0.88	19.7	18.9	17.9
0.78	22.6	19.4	18.2
0.68	25.0	20.4	18.6

For z = 5.4

and if ρ =	0.03	0.05	0.07
If y = 0.88	19.2	18.3	17.3
0.78	22.0	19.4	18.3
0.68	*	20.6	19.4

For z = 4.3

and if ρ =	0.03	0.05	0.07
If y = 0.88	19.1	18.3	19.1
0.78	23.0	19.8	21.1
0.68	23.9	23.9	*

Notes:

The table entries indicate the number of years the increment constructed should be designed to cover.

We note that, calculated on the basis described in the text, the optimal sizes change very little with the large change in z. We earlier calculated increment sizes on a somewhat different basis, in which the level of demand existing when an increment was built was explicitly included. On this basis there was a sharp increase in optimal sizes with the increase in z. The basis we adopt here seems "purer" since we cannot be picking up influences which should be reflected already in the choice of optimal D/Y ratio (the timing problem).

* Solutions not reliable.

If we agree to accept these rules of thumb as rough standards for optimal system expansion over time, what can we say about investment records of actual systems? Within the limits of the information available to them, do system managers generally seem to build too much or too little capacity? Do they plan to build too early or too late? Or are they, by some rough, intuitive process homing in on nearly optimal recommendations? We attempt to answer these questions by examining the world of practical water-system planning, the actual expansion histories of five Massachusetts systems, and the costs implied by these histories in the context of our planning model. These results may then be compared with the results achievable through the use of our rules of thumb.