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ECONOMIC-ENVIRONMENTAL-SECURITY TRANSFORM CURVES OF ELECTRIC POWER SYSTEM PRODUCTION SCHEDULES AND SIMULATIONS

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Report #6 November 1972

ENERGY LABORATORY

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This study was done in association with the Electric Power Systems Engineering Laboratory and the Department of Civil Engineering (Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics and the Civil Engineering Systems Laboratory).

ABSTRACT

A quasi-optimal technique ('quasi' in that the technique discards unreasonable optimums), realized by a dynamically evolving mixed integer program, is used to develop regional electric power maintenance and production sample schedules, as well as unit commitment sample schedules. This sophisticated, yet computationally feasible, method is used to develop the bulk dispatch schedules required to meet electric power demands at various preset reliability levels while controlling the associated dollar and environmental impact consequences.

This report considers a hypothetical system of about twelve power plants situated close to one another on the same river system. The maintenance and unit commitment scheduling mechanisms are used to display the tradeoffs which exist between the economic costs, environmental consequences and reliability levels of all possible optimum schedules. These tradeoff, or transform, surfaces are generated from *actual schedules for system operation*.

Also generated is a sample system simulation. Three possible generation expansion plans are compared and their potential operating performances are displayed. These specifically hypothesized expansion plans were tested on two different possible future load demand curves. The results show that there is great value in the use of an accurate dollar and environmental impact simulator.

Hypothetical data has been used, but effort has been made to make this data as representative as possible. The results of this project show that a great amount of flexibility is available to both the operations scheduler and the system expansion planner, and that the dollar costs, water and air pollution impacts cover a wide range of consequences. These results also show that it is probably very wasteful to operate or plan a system using any simple, single-minded measure of desirability as a decision making strategy.

Acknowledgements

The author would like to acknowledge the help of Prof. Fred C. Schweppe, M.I.T. Department of Electrical Engineering, who offered his insights and suggestions for the development of this material.

The help offered by Miss Nancy Huston is particularly appreciated, for her suggestions with respect to faster computation of this material and for her help in the lengthy process of reducing schedules to recognizable and meaningful representations of the processes and trends which took place.

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1. Introduction

A great problem to develop from this industrial era is the dilemma between the increasing demands for energy and the increasing demands that environmental qualities not be degraded. As the electric power industry assumes an ever increasing commitment to resolve the energy supply problem it is subjected to escalating societal pressures to:

(1) generate reliably a sufficient amount of electricity to meet any demands,

(2) retain or decrease its price rates, and

(3) minimize the impact of its generation efforts upon the ecosphere.

The solution to this problem will take a long and unremitting effort from all sectors of society. In the long-term (30 years) program of action must be included, among many other things, efforts to develop more efficient means of power generation and more efficient power utilization.[2] There can be no doubt that to reverse the trend of environmental deterioration a tremendous technological effort will be required.

There is, however, another aspect of the solution to the 'electric power-environment' dilemma which should be closely coordinated with (and is definitely not meant to be a replacement for) the technological advances, but is essentially a separate effort. This is the development of methods

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2. A detailed documentation of the course of action required from technological improvements is contained in a report by Philip Sporn, reference (1).

to assure the best possible operation of an imperfect power generation system. That is, until facilities which are perfectly compatible with the ecosystem are producing all of our power there must be a method for assuring that the imperfect plants are utilized in the least damaging manner. This effort breaks essentially into two segments. First, the plants must be sited to take the best advantage of the site options available.[3] Secondly, the operation of existing systems must be directed toward those objectives enumerated at the beginning of this section.

This optimum operation of existing systems is the overall project being undertaken in the author's Ph.D. thesis, of which this study is one portion.

1.1 Problem

For a more thorough description of the overall study of 'optimum operation of existing systems' of which this research effort is a part, the reader is directed to reference (4). However, a basic understanding of the interconnections involved can be gotten from figure 1.1-1 on the next page.

The annual optimum production and maintenance scheduler of figure 1.1-1 has been developed and is capable of generating optimum schedules for various dollar costs and environmental

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[3] This is a problem receiving a great deal of research effort, see for example reference (2). The author's particular project is also to be used as a simulation technique for the evaluation of specifically hypothesized expansion alternatives, as explained in reference (3).

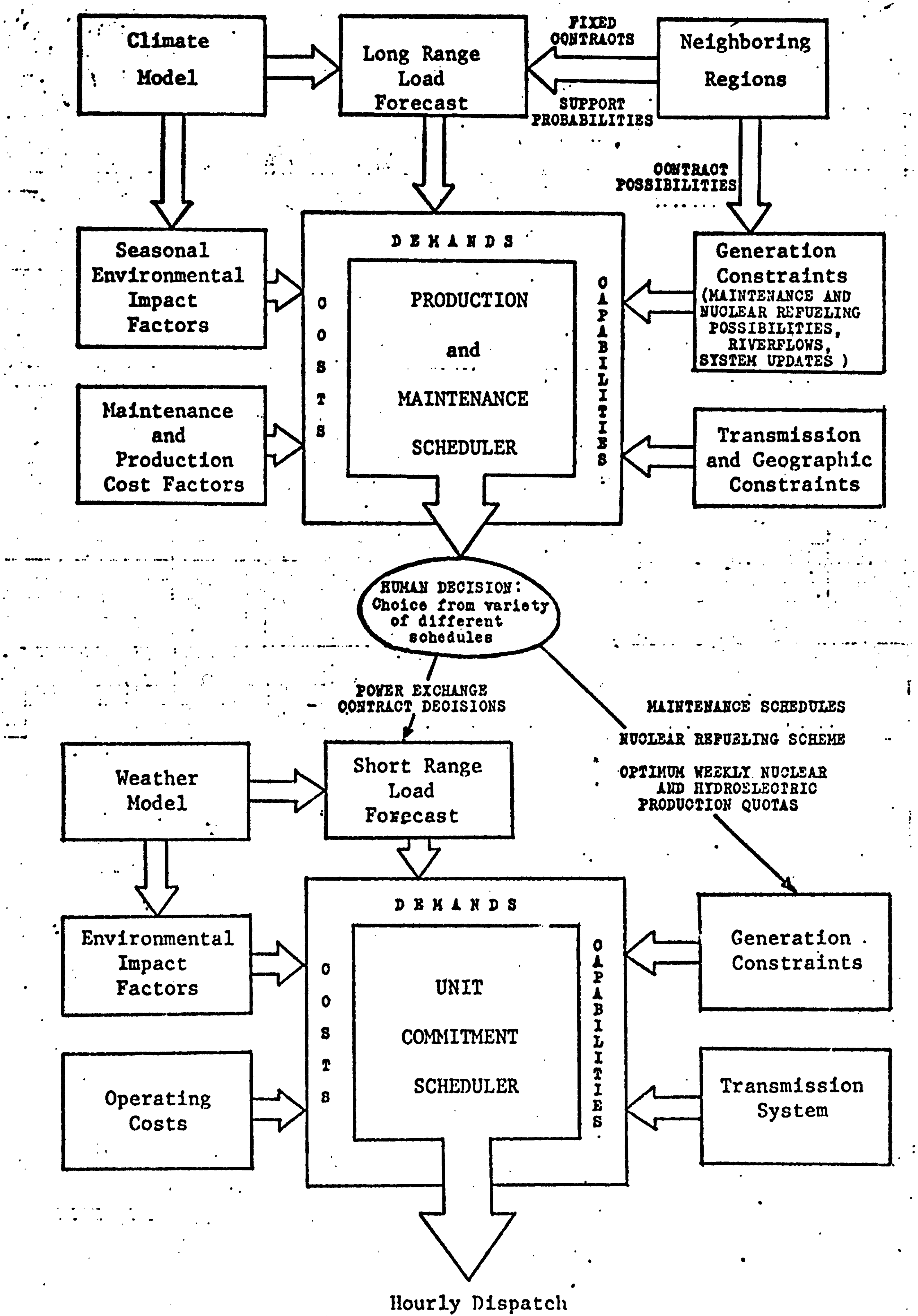

Figure 1.1-1 Block diagram representation of the overall system operation procedure

impact inputs. A similar output can be gotten from the existing unit commitment scheduler in the lower portion of figure 1.1-1.

In terms of input-output characteristics the schedule producing program can be described as follows:

GIVEN:

1. Generation characteristics
    - A. Capabilities and limitations
        - i. Types of facilities
        - ii. Output capacities
        - iii. Maintenance and refueling possibilities
    - B. Performance
        - i. Dollar costs per megawatt
        - ii. Costs of various maintenance and refueling schemes
        - iii. Air and water emissions per megawatt
2. Transmission characteristics
    - A. Capabilities and limitations
    - B. Costs
3. Weather model (probabilistic)
    - A. Air flow and temperature
    - B. Water flow and temperature
    - C. Upcoming weather patterns
4. Load model (probabilistic)
    - A. Long range
    - B. Short term forecasts
5. Interregional coordination
    - A. Power exchange contract possibilities (probabilistic)
    - B. Maintenance and production schedules

RESULTS:

1. Creates a variety of optimum maintenance and refueling schedules
2. Optimum unit commitment and hourly dispatch strategies
3. Performance in dollar costs, reliability and environmental impact

4. Shows system weaknesses, deficiencies and strengths
5. Makes power exchange contract decisions and coordinates system efforts with neighboring networks

This scheduler has the capability of handling a great variety of possible system components, including the wide range of plant types, sites and abatement possibilities - including plants with the capability of changing fuel types and qualities.

The exact uses and purposes of these schedulers, as well as the documentation and proper referencing of the arguments involved, can be found in references (5) and (6). For all intents and purposes this report should be viewed as a continuation of those reports. For any extensive study of the computer programs given in the appendices the reader is directed to the glossaries of computer program nomenclature in references (5) and (6).

A quick overview of the solution technique can be gotten from figure 1.1-2. Very briefly this technique can be described in terms of the block diagram representation in figure 1.1-3.

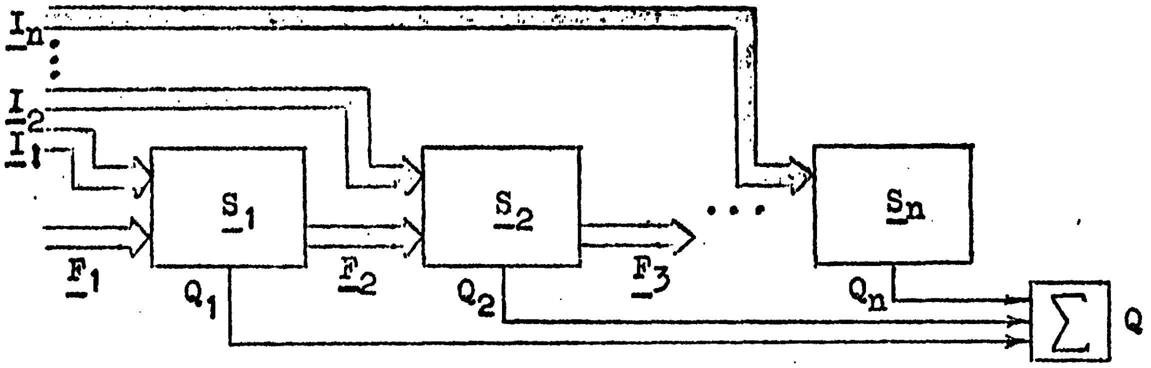

Figure 1.1-3 Block diagram of scheduling solution technique

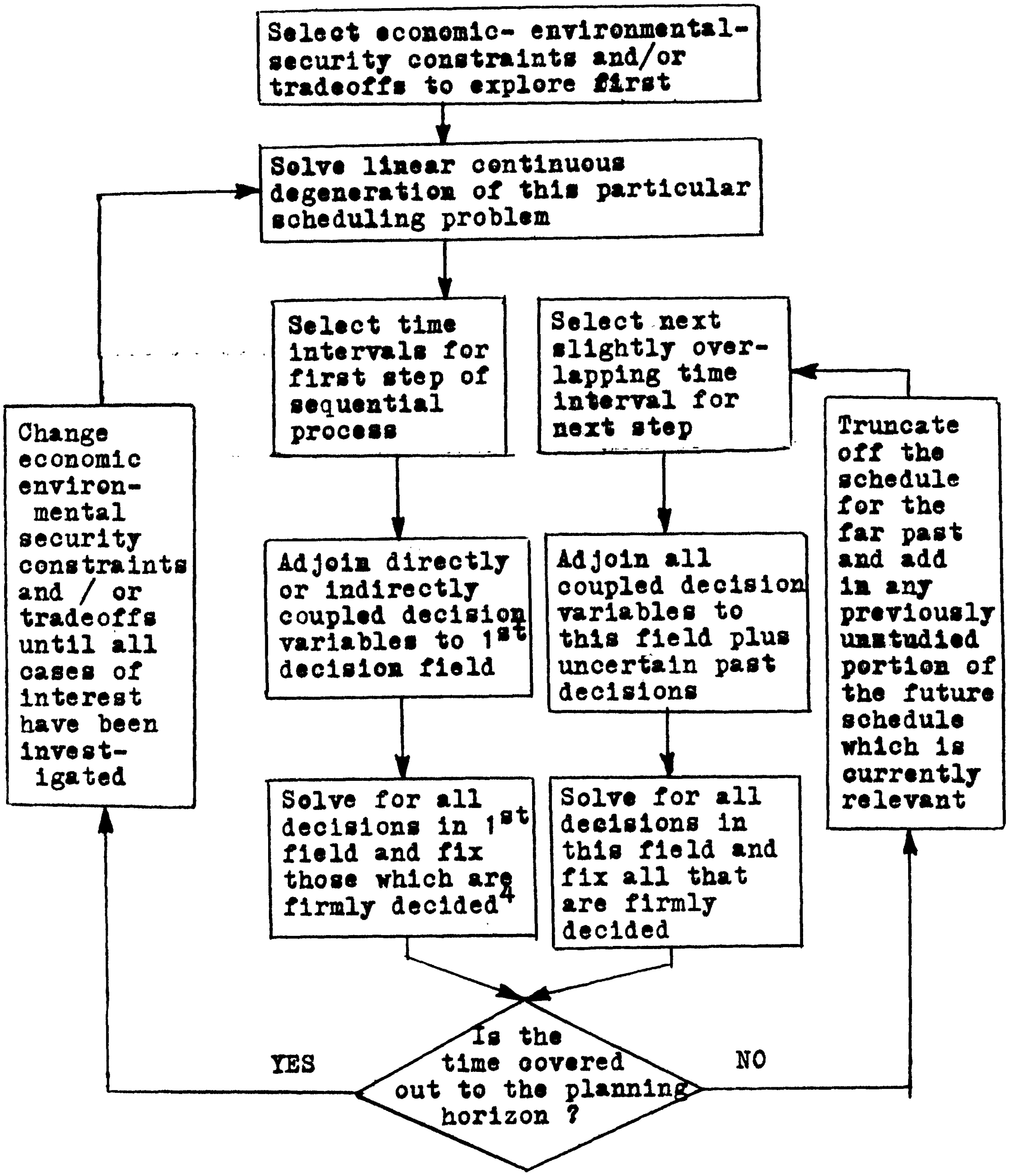

Figure 1.1-2 Flow chart of the dynamic evolving mixed integer program used in the scheduling process.

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[4] Here terms such as indirectly coupled and firm or uncertain refer to closeness to the optimum supporting hyperplane, or the propensity to change, as measured by the solution to the dual problem.

In figure 1.1-3, the sequential decision block diagram, $\underline{S}_1$, $\underline{S}_2$, etc. represent the portion of the schedule treated at each step in the computation. Q_1, Q_2, etc. are the costs, economic or environmental, that are contributed to the total system performance by the decisions made in the respective steps. The $\underline{I}_i$ represent the new material to be considered at each step, and the $\underline{F}_i$ represent the forwarded decisions and scheduling information.

Obviously, a problem which requires some explanation at this point is the method for quantification of the environmental impact. Two reports have been written by the author on this topic, references (7) and (8), thus only a brief explanation will be offered in this report. Roughly,

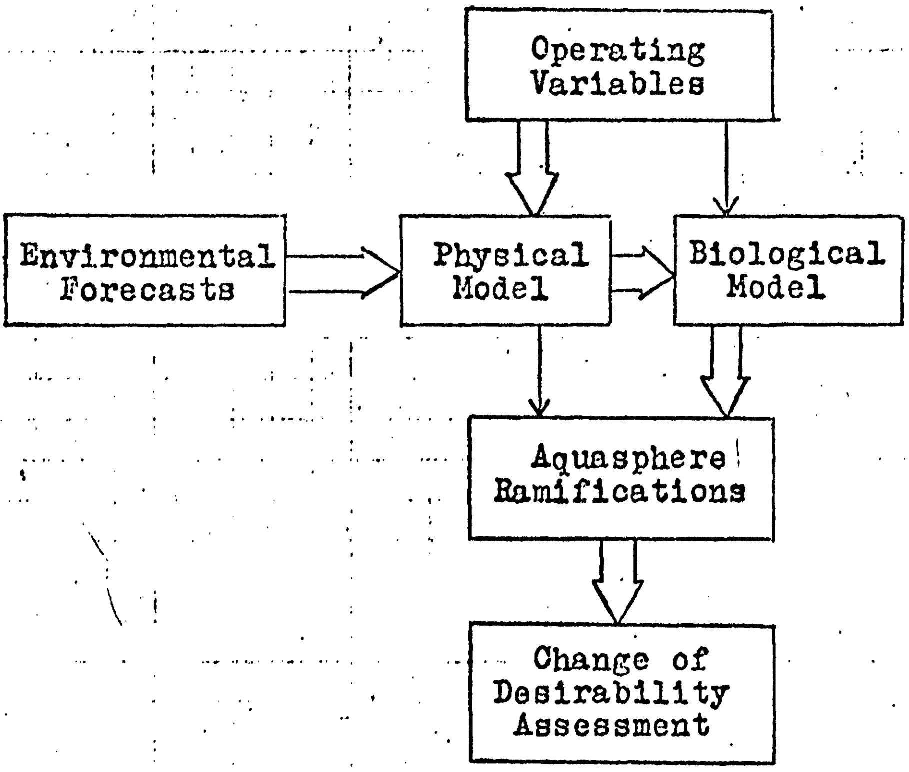

Figure 1.1-4 Simplified general systematic representation of aquasphere impact

these quantifications of impacts take into account the amount of pollutant created and scale this quantity by

(1) the speed of pollutant dispersion under existing or predicted physical system

(2) the severity of predicted pollutant levels from other sources

and (3) the size of the population affected.

Consider, for example, the quantification of the aquatic impact which can be broken down into a sequence of problems as represented in figure 1.1-4 on the previous page. The portion of this aquatic quantification which is the most difficult to determine is the Biological Model, which is further broken down in figure 1.1-5 on the following page.

So, in general, the quantification of environmental impact may be viewed as the taking of a probability of impact and convolving it with a probability of population affected.[5]

With this kind of a scheduling mechanism available several questions of interest arise. What sort of economic-environmental tradeoffs are available to a power system scheduler? What is the shape of these transform hyperplanes (i.e. tradeoff curves) and what does this shape indicate about strategies which should be pursued by a scheduler or a system expansion planner? What is the range of possible

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[5] A possible simplified, but relatively meaningless, approach to the problem of environmental impact quantification could be to measure aquatic impact in terms of BTUs introduced into the water system and atmospheric impact as tons of SO_2 into the air.

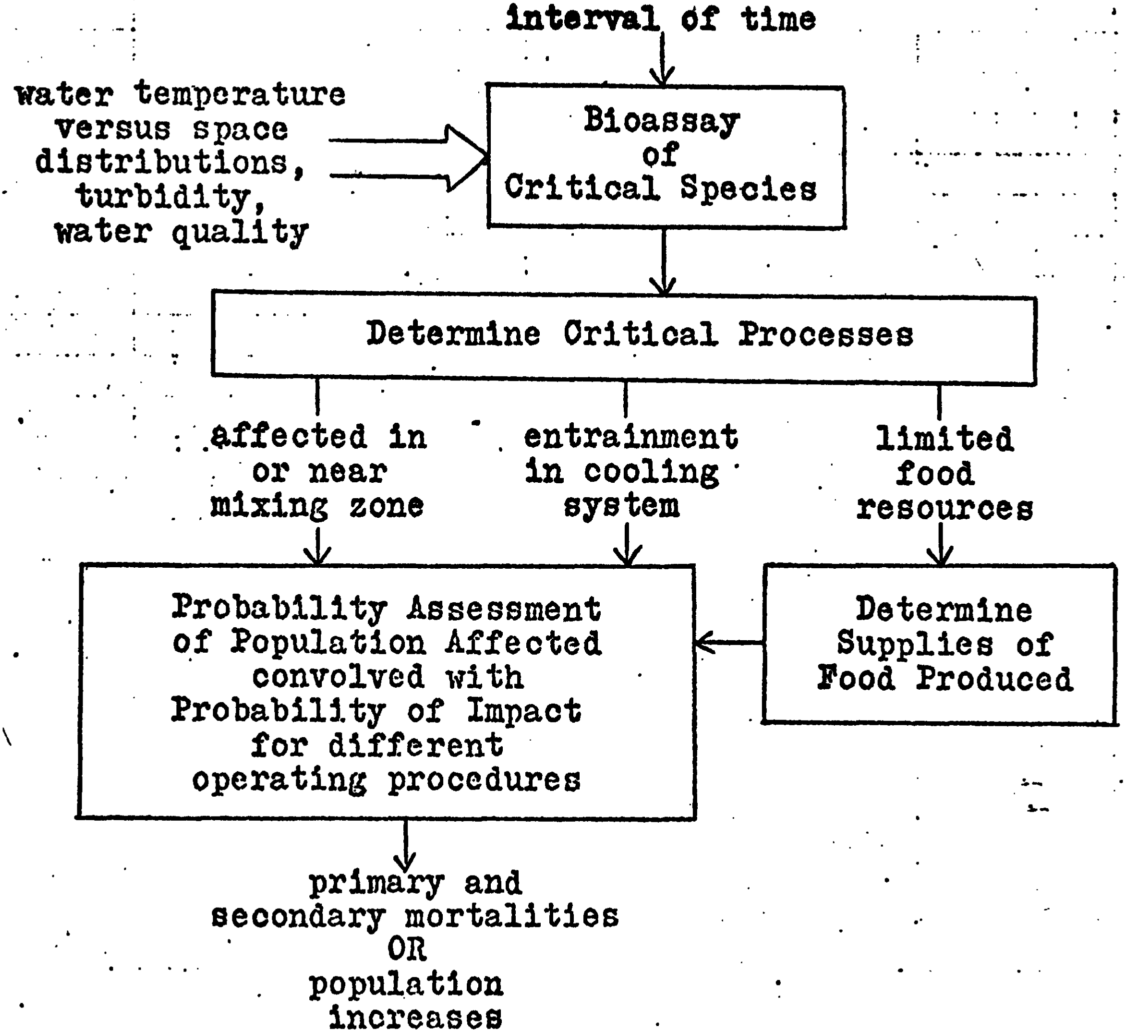

Figure 1.1-5 Block diagram of biological model in the aquatic impact quantifier

scheduling alternatives available for a power system? Answering these questions is the purpose of this study.

1.2 Historical Approaches

Studies even remotely related to this type of work are extremely rare. One paper[6] deals with the minute by minute dispatch of electric power using the usual λ, incremental

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[6] See reference (9).

cost, dispatch technique, however, substituting incremental tons of NO_x for the usual incremental dollar costs. This program is used for actual dispatching of power in the Los Angeles area where oxidizing pollutants, in particular NO_x, are a major health hazard.

Another paper[7] uses a somewhat more sophisticated system incremental cost technique, dispatching to minimize the pollution concentration at one or more particular points around the system. These two techniques deal only with part of the air pollution problem and are concerned only with the minute by minute dispatch problem. The hour by hour unit commitment problem is currently performed only with a dollar minimization objective, and the weekh by week maintenance scheduling is not even that sophisticated-being a 'fill-in-the-blank' problem as it is currently set up by schedulers.

1.3 Results

The results of this project show that there is an unusually large range of possible economic-environmental-security consequences available to the scheduler. The results of the unit commitment scheduling show that the dollar minimization currently used is probably an unwise criterion, with tremendous environmental gains available for incremental increases in dollar costs. Minimum environmental impact strategies, on the other hand, are

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[7] See reference (10).

probably equally unwise methods for operating a system.

Maintenance scheduling 'fill-in-the-blank' techniques appear to be very wasteful in terms of dollar losses and environmental impact consequences.

The computation and use of economic-environmental-security transform surfaces should be of interest to many people in addition to system schedulers and operators. The planning of system expansions should involve the careful placement and shaping of these surfaces by the inclusion of the appropriate system additions and abatement equipment. Environmentally and economically concerned regulatory agencies could develop a better understanding of the complexities and alternatives involved in operating a particular system - and hopefully *some* of the hard constraints imposed upon the system could be reevaluated in light of their consequences in constricting the full potentials of the system for the preservation of the environment and/or the minimization of economic consequences.

Thus, it appears that this scheduling technique and its associated tradeoff surfaces can be of great use.

1.4 Assumptions and Reservations

Although an attempt was made to make it representative the data used in this report is, nevertheless, hypothetical. Although the shapes of the tradeoff surfaces and their ranges are likely to remain nearly the same when real data is used, there will certainly be enough variations to make the input of real data a very worthwhile future project.

The nuclear-fossil-hydro strategies computed from the optimum schedules are meant only to serve as an indication of what trends took place in *this* particular scheduling problem - and are certainly not meant to be suggested strategies for any other system. Certainly each system will have its own characteristic tradeoff curves and strategies, with generalizations to be made very sparingly.

2. Tradeoff Surfaces of Unit Commitment Schedules

The following two chapters are primarily displays of data and results. No attempt is made to describe the workings of the scheduler used, this is contained in references (5) and (6), nor to elaborate or speculate on the material presented.

2.1 Description of the Sample System

There are eight active power plants in this system which are assumed to be located closely together, making a meaningful process of the combining of water or air pollution consequences from the various plants. This system is identical to that described in detail in reference (6), thus only a brief writeup will be given here.

The plants in the system include: plant 1, a relatively expensive (to operate) fossil fueled plant of 160 megawatts, with a moderately heavy air pollution factor (which varies of course as meteorological conditions change) and a cooling tower, thus, with very little thermal water pollution. Plant 2 is a 70 megawatt plant fueled with low sulfur content fossil fuel, making it slightly more expensive to operate but reducing its impact on the atmosphere. Plant 3 is a typical 120 megawatt fossil fueled unit. Plant 4 is an 80 megawatt gas turbine. Plant 5 is a 240 megawatt slightly cheaper fossil-fueled facility. Plant 6 is a 560 megawatt nuclear facility and 7 is a 100 megawatt hydroelectric station. Unit 8 is a pumped storage facility with 80% input efficiency, 83% output efficiency, 80 megawatts of storage capacity (maximum), and storage enough for the equivalent of 1000 megawatts hours of water power.

The nuclear, hydro and pumped hydre facilities have quotas for production and reservoir levels at the end of the week, with penalties associated with missing those targets.

The use of more than 400 megawatts of the large nuclear plant cues the need for added system spinning reserve requirements.

Emergency standby power support is available for purchase from an external source at a few prespecified times, otherwise all bulk interregional power transfers are assumed to have been previously settled (in the maintenance and production schedule) and the load demand curves have been adjusted in order to represent these transfers.

To take advantage of the decoupling of the different time intervals of the scheduling procedure, this problem was concerned only with the third step of a four step evolving process covering a week. The third step was concerned with hours 64 through 112 in the week, with step four, hours 120 - 168, being carried only in the linear mode of the scheduling process(this linear mode results in only about 1% error and thus does not make a great effect on the accuracy of the procedure). The time unit size in these third and fourth decision fields is eight hours. The exact data used for this system can be found in the program in Appendix A.

2.2 Demand and Spinning Reserve Requirements

The demand curve for the time interval of this problem is displayed in figure 2.2-1, showing the curves to be met for high, standard and low system reliability (load meeting probability) levels.

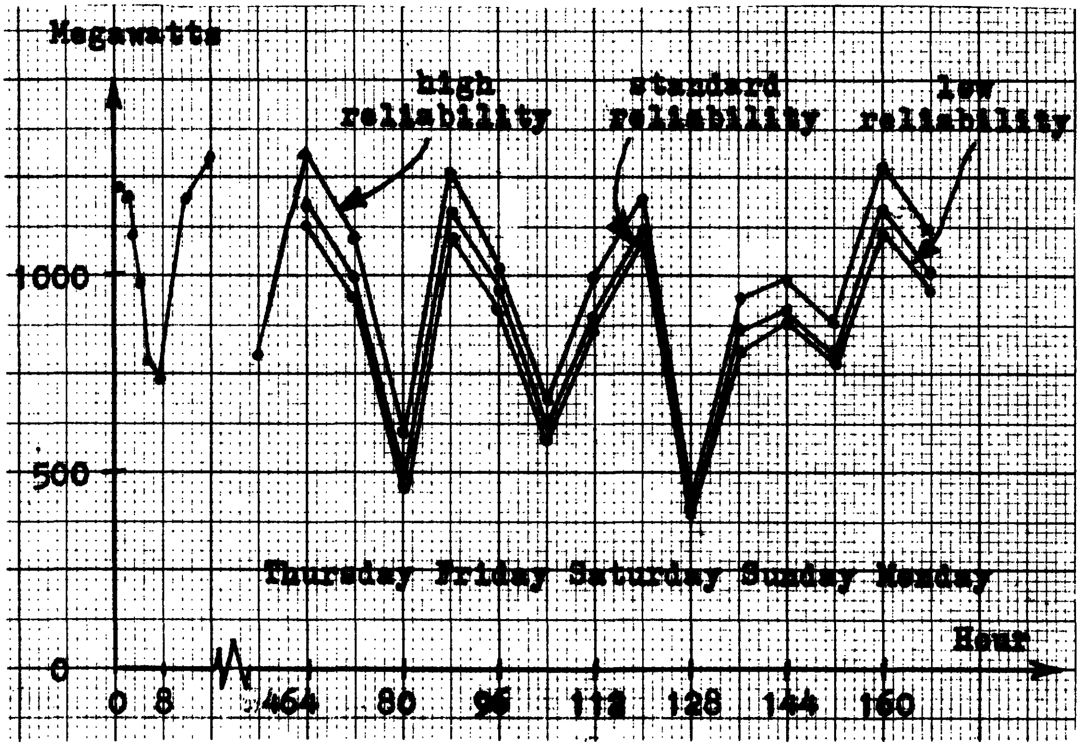

Figure 2.2-1 Demand-to-be-met curves for various reliability levels as used in the sample problem

The spinning reserve requirement (exclusive of the previously mentioned additive attachments cued by the nuclear unit) was set to be constant[8] at 305 megawatts,

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[8] It is possible, and in fact no more difficult, to use any amount of time variability in the spinning reserve requirement.

280 megawatts, and 255 megawatts for high, standard and low reliability levels, respectively.

Exact demand levels and spinning reserve requirements are listed in Appendix B.

2.3 A Sample Schedule

The following is an example of some of the most important information for one particular optimum schedule, the equal weighting of dollar costs, aquatic impacts and air impacts for a schedule meeting a standard reliability level.

The variables Q, QW, and QA represent the dollar, water and air costs of the schedule. QE, QV, and QB are the equal weightings of air and water, water and dollar, and dollars and air pollution, respectively. And QT is the equal weighting of all three consequences, which is the objective of this particular schedule.[9] D072, for example, is the megawatt-hour demand over the eight hours beginning at hour 72. SR072 is the associated spinning reserve requirement plus the demand requested at hour 72 and is also measured in megawatt-hours.

The dual activity associated with each demand level in the solution is the incremental cost of additional power that resulted in this particular schedule(cost here is dollars plus environmental units).

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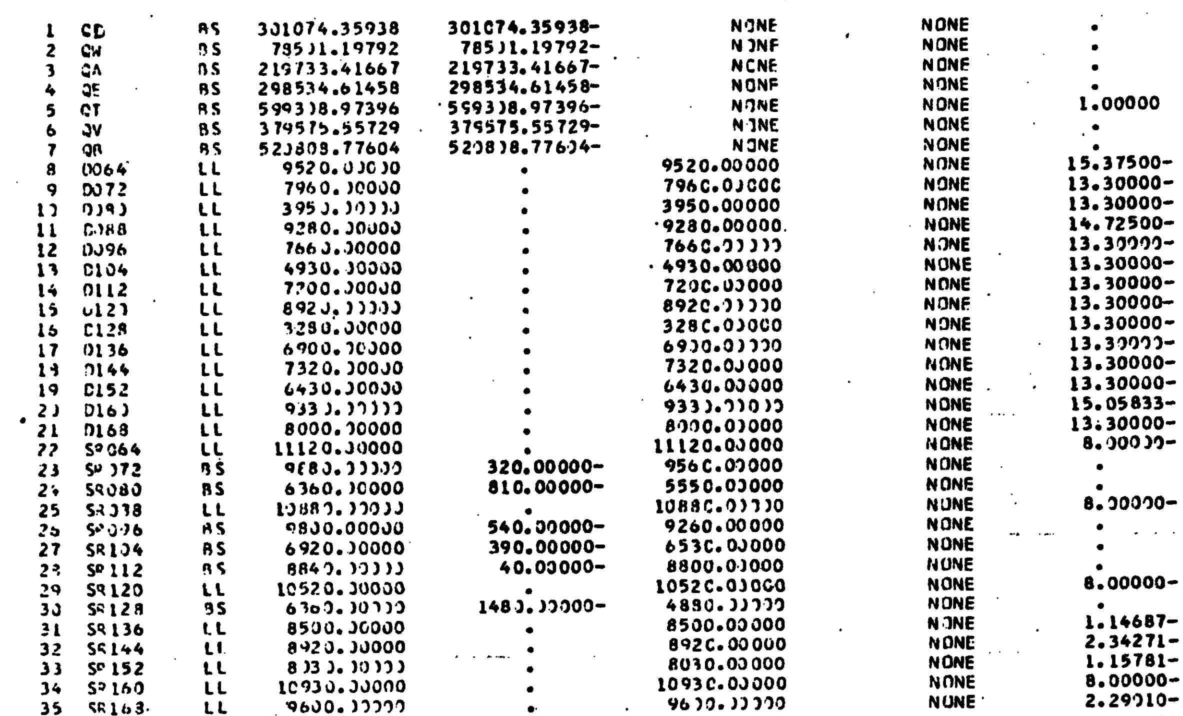
[9] The costs displayed in this program include costs above or below quota figures, for nuclear and hydro usage, and thus these fixed costs of those quotas should be added in:
QD +240,700 ; QW + 414,300 ; and QA + 67,600.

The variables such as A1064 represent the on=1, or off=0, status of plant 1 over interval 64. J and K variables represent extents of loading of the plants at the times indicated. A8 and G8 represent depletions or additions to the pumped storage level, where 1.0 activity represents maximum effort over the interval. HL064 is the level of the pumped storage facility at the 64th hour. The W's are indicators of the plants that have been started up in that particular time slot. ES represents the fractional use of the available emergency external support. OSN and USN, and OSH and USH represent the over and under usage of the nuclear and hydro weekly production quotas. For a more extensive description of the variables the reader is refered to reference (6).



```
NUMBER ...ROW..  AT  ...ACTIVITY...  SLACK ACTIVITY ..LOWER LIMIT. ..UPPER LIMIT. .DUAL ACTIVITY

    1  CD        BS  301074.35938    301074.35938-        NONE          NONE          .
    2  CW        BS   78501.19792     78501.19792-        NONE          NONE          .
    3  CA        BS  219733.41667    219733.41667-        NONE          NONE          .
    4  CE        BS  298534.61458    298534.61458-        NONE          NONE          .
    5  CT        BS  599308.97396    599308.97396-        NONE          NONE         1.00000
    6  CV        BS  379575.55729    379575.55729-        NONE          NONE          .
    7  CR        BS  520808.77604    520808.77604-        NONE          NONE          .
    8  D064      LL    9520.00000         .            9520.00000       NONE        15.37500-
    9  D072      LL    7960.00000         .            7960.00000       NONE        13.30000-
   10  D080      LL    3950.00000         .            3950.00000       NONE        13.30000-
   11  D088      LL    9280.00000         .            9280.00000       NONE        14.72500-
   12  D096      LL    7660.00000         .            7660.00000       NONE        13.30000-
   13  D104      LL    4930.00000         .            4930.00000       NONE        13.30000-
   14  D112      LL    7200.00000         .            7200.00000       NONE        13.30000-
   15  D120      LL    8920.00000         .            8920.00000       NONE        13.30000-
   16  D128      LL    3280.00000         .            3280.00000       NONE        13.30000-
   17  D136      LL    6900.00000         .            6900.00000       NONE        13.30000-
   18  D144      LL    7320.00000         .            7320.00000       NONE        13.30000-
   19  D152      LL    6430.00000         .            6430.00000       NONE        13.30000-
   20  D160      LL    9330.00000         .            9330.00000       NONE        15.05833-
   21  D168      LL    8000.00000         .            8000.00000       NONE        13.30000-
   22  SR064     LL   11120.00000         .           11120.00000       NONE         8.00000-
   23  SR072     BS    9880.00000     320.00000-       9560.00000       NONE          .
   24  SR080     BS    6360.00000     810.00000-       5550.00000       NONE          .
   25  SR088     LL   10880.00000         .           10880.00000       NONE         8.00000-
   26  SR096     BS    9800.00000     540.00000-       9260.00000       NONE          .
   27  SR104     BS    6920.00000     390.00000-       6530.00000       NONE          .
   28  SR112     BS    8840.00000      40.00000-       8800.00000       NONE          .
   29  SR120     LL   10520.00000         .           10520.00000       NONE         8.00000-
   30  SR128     BS    6360.00000    1480.00000-       4880.00000       NONE          .
   31  SR136     LL    8500.00000         .            8500.00000       NONE         1.14687-
   32  SR144     LL    8920.00000         .            8920.00000       NONE         2.34271-
   33  SR152     LL    8030.00000         .            8030.00000       NONE         1.15781-
   34  SR160     LL   10930.00000         .           10930.00000       NONE         8.00000-
   35  SR168     LL    9600.00000         .            9600.00000       NONE         2.29010-
```

Figure 2.3-1 Sample portion of one optimum schedule produced, minimizing dollar + air + water pollution for standard system reliability

```
NUMBER .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.
    36  NUTOT    EQ   51420.00000          .         51420.00000     51420.00000        13.30000
    37  HYTOT    EQ    7700.00000          .          7700.00000      7700.00000         8.80000
    38  PHTOT    EQ     160.00000          .           160.00000       160.00000         6.70000-

   277  A1056    EQ       1.00000          .             1.00000         1.00000          .
   278  A2056    EQ       1.00000          .             1.00000         1.00000          .
   279  A3056    EQ       1.00000          .             1.00000         1.00000          .
   280  A4056    EQ       1.00000          .             1.00000         1.00000          .
   281  A5056    EQ       1.00000          .             1.00000         1.00000          .
   282  A6056    EQ       1.00000          .             1.00000         1.00000          .
   283  A7056    EQ       1.00000          .             1.00000         1.00000       184.00000-
   284  HL056    EQ     100.00000          .           100.00000       100.00000        12.11406-
   285  J1064    UL       1.00000     8240.00000          .              1.00000      2830.00000-
   286  W1064    LL        .           330.00000          .              1.00000       330.00000
   287  J2064    UL       1.00000     3528.00000          .              1.00000      1392.00000-
   288  W2064    LL        .           112.00000          .              1.00000       112.00000
   289  J3064    LL        .          2580.00000          .              1.00000       120.00000
   290  K3064    LL        .          9560.00000          .              1.00000       950.00000
   291  W3064    LL        .           185.00000          .              1.00000       185.00000
   292  J4064    UL       1.00000     3584.00000          .              1.00000       106.00000-
   293  K4064    BS        .33333    3690.00000          .              1.00000          .
   294  W4064    LL        .           150.00000          .              1.00000       150.00000
   295  J5064    BS       1.00000     8420.00000          .              1.00000          .
   296  K5064    LL        .          9188.00000          .              1.00000      4268.00000
   297  W5064    LL        .           402.00000          .              1.00000       402.00000
   298  J6064    UL       1.00000          .               .              1.00000      8300.00000-
   299  W6064    LL        .          1019.00000          .              1.00000      1019.00000
   300  J7064    UL       1.00000          .               .              1.00000      4997.00000-
   301  W7064    BS        .           184.00000          .              1.00000          .
   302  A8064    BS        .15625          .               .              1.00000          .
   303  G8064    LL        .               .               .              1.00000      4055.00000
   304  HL064    LL        .               .               .           1000.00000          .25333
   305  W8064    BS        .15625      119.00000          .              1.00000          .
   306  FS064    BS        .22667    24000.00000          .              1.00000          .
   307  J1072    BS       1.00000     8260.00000          .              1.00000          .
   308  W1072    BS        .           330.00000          .              1.00000          .
   309  J2072    BS        .          3568.00000          .              1.00000          .
   310  W2072    LL        .           112.00000          .              1.00000       112.00000
   311  J3072    LL        .          2630.00000          .              1.00000       502.00000
   312  K3072    LL        .          9660.00000          .              1.00000      2212.00000
   313  W3072    LL        .           185.00000          .              1.00000       185.00000
   314  J4072    LL        .          3624.00000          .              1.00000       432.00000
   315  K4072    LL        .          3730.00000          .              1.00000       538.00000
   316  W4072    LL        .           150.00000          .              1.00000       150.00000
   317  J5072    BS       1.00000     8500.00000          .              1.00000          .
   318  K5072    LL        .          9378.00000          .              1.00000      5122.00000
   319  W5072    LL        .           402.00000          .              1.00000       402.00000
   320  J6072    BS        .85000          .               .              1.00000          .
   321  W6072    LL        .          1019.00000          .              1.00000      1019.00000
   322  J7072    UL       1.00000          .               .              1.00000      3420.00000-
   323  W7072    LL        .           184.00000          .              1.00000       184.00000
   324  A8072    LL        .               .               .              1.00000       781.26667
   325  G8072    LL        .               .               .              1.00000      2623.53333
   326  HL072    BS        .               .               .           1000.00000          .
   327  W8072    LL        .           119.00000          .              1.00000       119.00000
   328  FS072    LL        .         24000.00000          .              1.00000     24000.00000
   329  J1080    UL       1.00000     7240.00000          .              1.00000      2291.00000-
   330  W1080    BS        .           330.00000          .              1.00000          .
   331  J2080    BS        .          3608.00000          .              1.00000          .
   332  W2080    BS        .           112.00000          .              1.00000          .
   333  J3080    LL        .          2690.00000          .              1.00000       562.00000
   334  K3080    LL        .          9780.00000          .              1.00000      2332.00000
   335  W3080    LL        .           185.00000          .              1.00000       185.00000
   336  J4080    LL        .          3684.00000          .              1.00000       492.00000
   337  K4080    LL        .          3790.00000          .              1.00000       598.00000
   338  W4080    LL        .           150.00000          .              1.00000       150.00000
   339  J5080    LL        .          8740.00000          .              1.00000      4826.00000
   340  K5080    LL        .          9588.00000          .              1.00000      5332.00000
   341  W5080    LL        .           402.00000          .              1.00000       402.00000
   342  J6080    BS        .34750          .               .              1.00000          .
   343  W6080    LL        .          1019.00000          .              1.00000       548.00000
   344  J7080    UL       1.00000          .               .              1.00000      3420.00000-
   345  W7080    LL        .           184.00000          .              1.00000        65.00000
   346  A8080    LL        .               .               .              1.00000       713.93333
   347  G8080    LL        .               .               .              1.00000      2623.53333
```

Figure 2.3-1 (continued) Sample portion of one optimum schedule, showing nuclear, hydro, and pumped hydro weekly quotas and initial conditions, and part of the final schedule.

```
NUMBER  .COLUMN.  AT  ...ACTIVITY...  ...INPUT COST..  ...LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.
  348   HL080     BS        .                .               .          1000.00000            .
  349   W8080     LL        .            119.00000           .             1.00000      119.00000
  350   J1088     BS     1.00000      6830.00000           .             1.00000            .
  351   W1088     LL        .            330.00000           .             1.00000      330.00000
  352   J2088     UL     1.00000      3518.00000           .             1.00000     1194.00000-
  353   W2088     UL     1.00000       112.00000           .             1.00000     4213.00000-
  354   J3088     LL        .          2580.00000           .             1.00000      224.00000
  355   K3088     LL        .          9560.00000           .             1.00000     1314.00000
  356   W3088     UL     1.00000       185.00000           .             1.00000      904.00000-
  357   J4088     BS      .66667      3534.00000           .             1.00000            .
  358   K4088     LL        .          3660.00000           .             1.00000      126.00000
  359   W4088     BS     1.00000       150.00000           .             1.00000            .
  360   J5088     UL     1.00000      8520.00000           .             1.00000            .
  361   K5088     LL        .          9468.00000           .             1.00000     4756.00000
  362   W5088     BS     1.00000       402.00000           .             1.00000            .
  363   J6088     BS     1.00000             .               .             1.00000            .
  364   W6088     BS        .          1019.00000           .             1.00000            .
  365   J7088     UL     1.00000             .               .             1.00000     4503.00000-
  366   W7088     BS        .           184.00000           .             1.00000            .
  367   A8088     BS        .                .               .             1.00000            .
  368   G8088     LL        .                .               .             1.00000     3717.93333
  369   HL088     BS        .                .               .          1000.00000            .
  370   W8088     LL        .           119.00000           .             1.00000       51.66667
  371   ES088     BS      .14667     24000.00000           .             1.00000            .
  372   J1096     UL     1.00000      7740.00000           .             1.00000     1244.00000-
  373   W1096     LL        .           330.00000           .             1.00000      330.00000
  374   J2096     UL     1.00000      3508.00000           .             1.00000       86.00000-
  375   W2096     LL        .           112.00000           .             1.00000      112.00000
  376   J3096     LL        .          2590.00000           .             1.00000      462.00000
  377   K3096     LL        .          9520.00000           .             1.00000     2072.00000
  378   W3096     LL        .           185.00000           .             1.00000      185.00000
  379   J4096     LL        .          3554.00000           .             1.00000      986.50000
  380   K4096     LL        .          3680.00000           .             1.00000     1112.50000
  381   W4096     LL        .           150.00000           .             1.00000      150.00000
  382   J5096     BS     1.00000      8270.00000           .             1.00000            .
  383   K5096     LL        .          9038.00000           .             1.00000     4782.00000
  384   W5096     LL        .           402.00000           .             1.00000      402.00000
  385   J6096     BS      .67500             .               .             1.00000            .
  386   W6096     LL        .          1019.00000           .             1.00000     1019.00000
  387   J7096     UL     1.00000             .               .             1.00000     3420.00000-
  388   W7096     LL        .           184.00000           .             1.00000      184.00000
  389   A8096     LL        .                .               .             1.00000      900.26667
  390   G8096     LL        .                .               .             1.00000     2623.53333
  391   HL096     BS        .                .               .          1000.00000            .
  392   W8096     BS        .           119.00000           .             1.00000            .
  393   J1104     BS     1.00000      8230.00000           .             1.00000            .
  394   W1104     LL        .           330.00000           .             1.00000      330.00000
  395   J2104     UL     1.00000      3518.00000           .             1.00000      144.00000-
  396   W2104     BS        .           112.00000           .             1.00000            .
  397   J3104     LL        .          2630.00000           .             1.00000      502.00000
  398   K3104     LL        .          9600.00000           .             1.00000     2152.00000
  399   W3104     LL        .           185.00000           .             1.00000      185.00000
  400   J4104     LL        .          3554.00000           .             1.00000      860.00000
  401   K4104     LL        .          3680.00000           .             1.00000      986.00000
  402   W4104     LL        .           150.00000           .             1.00000      150.00000
  403   J5104     BS        .          8070.00000           .             1.00000            .
  404   K5104     LL        .          8788.00000           .             1.00000     4532.00000
  405   W5104     LL        .           402.00000           .             1.00000      402.00000
  406   J6104     BS      .45250             .               .             1.00000            .
  407   W6104     LL        .          1019.00000           .             1.00000      960.00000
  408   J7104     UL     1.00000             .               .             1.00000     3420.00000-
  409   W7104     LL        .           184.00000           .             1.00000      164.00000
  410   A8104     LL        .                .               .             1.00000      662.26667
  411   G8104     LL        .                .               .             1.00000     2623.53333
  412   HL104     BS        .                .               .          1000.00000            .
  413   W8104     LL        .           119.00000           .             1.00000      119.00000
  414   J1112     UL     1.00000      8520.00000           .             1.00000      114.00000-
  415   W1112     LL        .           330.00000           .             1.00000      330.00000
  416   J2112     UL     1.00000      3498.00000           .             1.00000      562.00000-
  417   W2112     LL        .           112.00000           .             1.00000      112.00000
  418   J3112     LL        .          2530.00000           .             1.00000      922.50000
  419   K3112     LL        .          9400.00000           .             1.00000     2472.50000
  420   W3112     BS        .           185.00000           .             1.00000            .
  421   J4112     LL        .          3484.00000           .             1.00000      894.00000
  422   K4112     LL        .          3630.00000           .             1.00000     1040.00000
  423   W4112     BS        .           150.00000           .             1.00000            .
  424   J5112     BS     1.00000      7970.00000           .             1.00000            .
  425   K5112     LL        .          8638.00000           .             1.00000     4382.00000
  426   W5112     BS     1.00000       402.00000           .             1.00000            .
  427   J6112     BS      .62000             .               .             1.00000            .
```

Figure 2.3-1 (continued) Sample portion of one optimum schedule

```
NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   428  W6112     LL        .         1019.00000        .               1.00000       448.00000
   429  J7112     UL     1.00000          .             .               1.00000      3420.00000-
   430  W7112     LL        .          184.00000        .               1.00000        20.00000
   431  A8112     LL        .             .             .               1.00000       781.26667
   432  G8112     LL        .             .             .               1.00000      2623.53333
   433  HL112     BS        .             .             .            1000.00000          .
   434  W8112     BS        .          119.00000        .               1.00000          .
   435  A1120     UL     1.00000      8980.00000        .               1.00000      8378.00000-
   436  J1120     UL     1.00000      8690.00000        .               1.00000       886.00000-
   437  W1120     BS        .          330.00000        .               1.00000          .
   438  A2120     UL     1.00000      3941.00000        .               1.00000      3619.00000-
   439  J2120     UL     1.00000      3538.00000        .               1.00000       718.00000-
   440  W2120     BS        .          112.00000        .               1.00000          .
   441  A3120     UL     1.00000      4051.00000        .               1.00000      6636.00000-
   442  J3120     LL        .         2590.00000        .               1.00000       462.00000
   443  K3120     LL        .         9500.00000        .               1.00000      2052.00000
   444  W3120     BS     1.00000       185.00000        .               1.00000          .
   445  A4120     UL     1.00000      3421.00000        .               1.00000      3677.00000-
   446  J4120     LL        .         3484.00000        .               1.00000       292.00000
   447  K4120     LL        .         3600.00000        .               1.00000       408.00000
   448  W4120     BS     1.00000       150.00000        .               1.00000          .
   449  A5120     UL     1.00000     17500.00000        .               1.00000     10708.00000-
   450  J5120     BS     1.00000      8030.00000        .               1.00000          .
   451  B5120     LL        .         8030.00000        .               1.00000          .
   452  K5120     LL        .         8738.00000        .               1.00000      4482.00000
   453  W5120     BS        .          402.00000        .               1.00000          .
   454  A6120     UL     1.00000       490.00000        .               1.00000     33162.00000-
   455  J6120     BS      .95000          .             .               1.00000          .
   456  W6120     BS        .         1019.00000        .               1.00000          .
   457  A7120     UL     1.00000       211.00000        .               1.00000      6283.00000-
   458  J7120     UL     1.00000          .             .               1.00000      3420.00000-
   459  W7120     BS        .          184.00000        .               1.00000          .
   460  A8120     LL        .             .             .               1.00000       781.26667
   461  G8120     LL        .             .             .               1.00000      2623.53333
   462  HL120     BS        .             .             .            1000.00000          .
   463  W8120     BS        .          119.00000        .               1.00000          .
   464  E5120     BS      .02667     24000.00000        .               1.00000          .
   465  A1128     UL     1.00000      8327.00000        .               1.00000       747.00000-
   466  J1128     BS     1.00000      8280.00000        .               1.00000          .
   467  W1128     LL        .          330.00000        .               1.00000       330.00000
   468  A2128     LL        .         4164.00000        .               1.00000       192.00000
   469  J2128     BS        .         3588.00000        .               1.00000          .
   470  W2128     LL        .          112.00000        .               1.00000       112.00000
   471  A3128     LL        .         4317.00000        .               1.00000       940.00000
   472  J3128     LL        .         2660.00000        .               1.00000       532.00000
   473  K3128     LL        .         9640.00000        .               1.00000      2192.00000
   474  W3128     LL        .          185.00000        .               1.00000       185.00000
   475  A4128     BS        .         3359.00000        .               1.00000          .
   476  J4128     LL        .         3474.00000        .               1.00000       822.50000
   477  K4128     LL        .         3610.00000        .               1.00000       958.50000
   478  W4128     LL        .          150.00000        .               1.00000       150.00000
   479  A5128     BS        .        17423.00000        .               1.00000          .
   480  J5128     LL        .         8130.00000        .               1.00000      3871.00000
   481  B5128     LL        .         8130.00000        .               1.00000      3871.00000
   482  K5128     LL        .         8778.00000        .               1.00000      4522.00000
   483  W5128     LL        .          402.00000        .               1.00000       402.00000
   484  A6128     BS     1.00000       588.00000        .               1.00000          .
   485  J6128     BS      .18000          .             .               1.00000          .
   486  W6128     LL        .         1019.00000        .               1.00000       588.00000
   487  A7128     BS     1.00000       266.00000        .               1.00000          .
   488  J7128     UL     1.00000          .             .               1.00000      3420.00000-
   489  W7128     LL        .          184.00000        .               1.00000       '86.00000
   490  A8128     LL        .             .             .               1.00000       781.26667
   491  G8128     LL        .             .             .               1.00000      2623.53333
   492  HL128     BS        .             .             .            1000.00000          .
   493  W8128     BS        .          119.00000        .               1.00000          .
   494  A1136     UL     1.00000      8362.00000        .               1.00000      2220.00000-
   495  J1136     BS     1.00000      8210.00000        .               1.00000          .
   496  W1136     BS        .          330.00000        .               1.00000          .
   497  A2136     UL     1.00000      3182.00000        .               1.00000       540.25000-
   498  J2136     UL     1.00000      3548.00000        .               1.00000       708.00000-
   499  W2136     BS     1.00000       112.00000        .               1.00000          .
   500  A3136     BS     1.00000      4140.00000        .               1.00000          .
   501  J3136     LL        .         2620.00000        .               1.00000       492.00000
   502  K3136     LL        .         9630.00000        .               1.00000      2182.00000
   503  W3136     BS     1.00000       185.00000        .               1.00000          .
   504  A4136     BS      .96875      2862.00000        .               1.00000          .
   505  J4136     LL        .         3504.00000        .               1.00000       312.00000
   506  K4136     LL        .         3630.00000        .               1.00000       438.00000
   507  W4136     BS      .96875       150.00000        .               1.00000          .
```

Figure 2.3-1 (continued) **Sample portion of one optimum schedule**

```
NUMBER  .COLUMN.  AT   ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.
  508   A5136     BS        .           17620.00000         .            1.00000             .
  509   J5136     LL        .            8020.00000         .            1.00000        2158.00000
  510   B5136     BS        .            8020.00000         .            1.00000             .
  511   K5136     LL        .            8688.00000         .            1.00000        6590.00000
  512   W5136     BS        .             402.00000         .            1.00000             .
  513   A6136     UL     1.00000          430.00000         .            1.00000        3459.62500-
  514   J6136     BS      .84625              .             .            1.00000             .
  515   W6136     BS        .            1019.00000         .            1.00000             .
  516   A7136     UL     1.00000          238.00000         .            1.00000        4279.50000-
  517   J7136     BS     1.00000              .             .            1.00000             .
  518   W7136     BS        .             184.00000         .            1.00000             .
  519   A8136     LL        .                 .             .            1.00000         781.26667
  520   G8136     LL        .                 .             .            1.00000        2623.53333
  521   HL136     BS        .                 .             .         1000.00000             .
  522   W8136     BS        .             119.00000         .            1.00000             .
  523   A1144     UL     1.00000         7848.00000         .            1.00000        4504.66667-
  524   J1144     BS     1.00000         7340.00000         .            1.00000             .
  525   W1144     BS        .             330.00000         .            1.00000             .
  526   A2144     UL     1.00000         3768.00000         .            1.00000         735.91667-
  527   J2144     UL     1.00000         3588.00000         .            1.00000         668.00000-
  528   W2144     LL        .             112.00000         .            1.00000         112.00000
  529   A3144     UL     1.00000         4207.00000         .            1.00000        1387.00000-
  530   J3144     LL        .            2710.00000         .            1.00000         582.00000
  531   K3144     LL        .            9820.00000         .            1.00000        2372.00000
  532   W3144     LL        .             185.00000         .            1.00000         153.00000
  533   A4144     UL     1.00000         3193.00000         .            1.00000         284.33333-
  534   J4144     LL        .            3554.00000         .            1.00000         362.00000
  535   K4144     LL        .            3680.00000         .            1.00000         488.00000
  536   W4144     BS      .03125          150.00000         .            1.00000             .
  537   A5144     BS      .20833        17306.00000         .            1.00000             .
  538   J5144     BS      .20833         8070.00000         .            1.00000             .
  539   B5144     LL        .            8070.00000         .            1.00000             .
  540   K5144     LL        .            8908.00000         .            1.00000        4652.00000
  541   W5144     BS      .20833          402.00000         .            1.00000             .
  542   A6144     UL     1.00000          544.00000         .            1.00000        9482.79167-
  543   J6144     BS      .86667              .             .            1.00000             .
  544   W6144     LL        .            1019.00000         .            1.00000        1019.00000
  545   A7144     UL     1.00000          217.00000         .            1.00000        5257.16667-
  546   J7144     BS     1.00000              .             .            1.00000             .
  547   W7144     BS        .             184.00000         .            1.00000             .
  548   A8144     LL        .                 .             .            1.00000         781.26667
  549   G8144     LL        .                 .             .            1.00000        2623.53333
  550   HL144     BS        .                 .             .         1000.00000             .
  551   W8144     BS        .             119.00000         .            1.00000             .
  552   A1152     UL     1.00000         6856.00000         .            1.00000        4860.00000-
  553   J1152     BS     1.00000         7120.00000         .            1.00000             .
  554   W1152     LL        .             330.00000         .            1.00000         330.00000
  555   A2152     UL     1.00000         3594.00000         .            1.00000         546.37500-
  556   J2152     BS     1.00000         3668.00000         .            1.00000             .
  557   W2152     LL        .             112.00000         .            1.00000         112.00000
  558   A3152     BS     1.00000         4264.00000         .            1.00000             .
  559   J3152     LL        .            2740.00000         .            1.00000         612.00000
  560   K3152     LL        .            9910.00000         .            1.00000        2462.00000
  561   W3152     BS        .             185.00000         .            1.00000             .
  562   A4152     BS      .23438         3019.00000         .            1.00000             .
  563   J4152     LL        .            3524.00000         .            1.00000         332.00000
  564   K4152     LL        .            3660.00000         .            1.00000         468.00000
  565   W4152     LL        .             150.00000         .            1.00000         150.00000
  566   A5152     BS        .           17529.00000         .            1.00000             .
  567   J5152     LL        .            8090.00000         .            1.00000        1714.00000
  568   B5152     LL        .            8090.00000         .            1.00000        1714.00000
  569   K5152     LL        .            8938.00000         .            1.00000        4682.00000
  570   W5152     LL        .             402.00000         .            1.00000         402.00000
  571   A6152     UL     1.00000          486.00000         .            1.00000        4469.43750-
  572   J6152     BS      .75813              .             .            1.00000             .
  573   W6152     LL        .            1019.00000         .            1.00000        1019.00000
  574   A7152     UL     1.00000          252.00000         .            1.00000         854.25000-
  575   J7152     UL     1.00000              .             .            1.00000        3420.00000-
  576   W7152     BS        .             184.00000         .            1.00000             .
  577   A8152     LL        .                 .             .            1.00000         781.26667
  578   G8152     LL        .                 .             .            1.00000        2623.53333
  579   HL152     BS        .                 .             .         1000.00000             .
  580   W8152     BS        .             119.00000         .            1.00000             .
```

Figure 2.3-1 (continued) Sample portion of one optimum schedule

```
NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

   581  A1160     UL         1.00000      7157.00000          .              1.00000    11185.66667-
   582  J1160     UL         1.00000      7250.00000          .              1.00000     3592.00000-
   583  W1160     BS          .            330.00000          .              1.00000        .
   584  A2160     UL         1.00000      3717.00000          .              1.00000     4377.00000-
   585  J2160     UL         1.00000      3598.00000          .              1.00000     1220.66667-
   586  W2160     BS          .            112.00000          .              1.00000        .
   587  A3160     UL         1.00000      4357.00000          .              1.00000     6791.50000-
   588  J3160     LL          .           2700.00000          .              1.00000      290.66667
   589  K3160     LL          .           9860.00000          .              1.00000     1427.33333
   590  W3160     LL          .            185.00000          .              1.00000       39.50000
   591  A4160     UL         1.00000      3502.00000          .              1.00000     3877.33333-
   592  J4160     BS          .87500      3614.00000          .              1.00000        .
   593  K4160     LL          .           3750.00000          .              1.00000      136.00000
   594  W4160     BS          .76562       150.00000          .              1.00000        .
   595  A5160     UL         1.00000     17737.00000          .              1.00000    13144.33333-
   596  J5160     BS         1.00000      8170.00000          .              1.00000        .
   597  R5160     LL          .           8170.00000          .              1.00000        .
   598  K5160     LL          .           8588.00000          .              1.00000     4169.33333
   599  W5160     BS         1.00000       402.00000          .              1.00000        .
   600  A6160     UL         1.00000       507.00000          .              1.00000    35596.00000-
   601  J6160     UL         1.00000         .                .              1.00000     7033.33333-
   602  W6160     LL          .           1019.00000          .              1.00000     1019.00000
   603  A7160     UL         1.00000       304.00000          .              1.00000     6346.33333-
   604  J7160     UL         1.00000         .                .              1.00000     4756.33333-
   605  W7160     BS          .            184.00000          .              1.00000        .
   606  A8160     BS          .              .                .              1.00000        .
   607  G8160     LL          .              .                .              1.00000     3973.93333
   608  HL160     BS          .              .                .           1000.00000        .
   609  W8160     BS          .            119.00000          .              1.00000        .
   610  ES160     BS          .16333     24000.00000          .              1.00000        .
   611  A1168     UL         1.00000      6600.00000          .              1.00000     6215.33333-
   612  J1168     BS         1.00000      7140.00000          .              1.00000        .
   613  W1168     LL          .            330.00000          .              1.00000      330.00000
   614  A2168     UL         1.00000      3620.00000          .              1.00000      742.45833-
   615  J2168     UL         1.00000      3588.00000          .              1.00000      668.00000-
   616  W2168     BS          .            112.00000          .              1.00000        .
   617  A3168     UL         1.00000      4424.00000          .              1.00000      966.50000-
   618  J3168     LL          .           2710.00000          .              1.00000      582.00000
   619  K3168     LL          .           9900.00000          .              1.00000     2452.00000
   620  W3168     LL          .            185.00000          .              1.00000      185.00000
   621  A4168     UL         1.00000      3381.00000          .              1.00000      212.66667-
   622  J4168     LL          .           3644.00000          .              1.00000      452.00000
   623  K4168     LL          .           3780.00000          .              1.00000      588.00000
   624  W4168     LL          .            150.00000          .              1.00000      150.00000
   625  A5168     BS          .56250     17567.00000          .              1.00000        .
   626  J5168     BS          .56250      8110.00000          .              1.00000        .
   627  R5168     BS          .           8110.00000          .              1.00000        .
   628  K5168     LL          .           8788.00000          .              1.00000     4532.00000
   629  W5168     LL          .            402.00000          .              1.00000      402.00000
   630  A6168     UL         1.00000       449.00000          .              1.00000     8333.64583-
   631  J6168     BS          .89500         .                .              1.00000        .
   632  W6168     BS          .           1019.00000          .              1.00000        .
   633  A7168     UL         1.00000       247.00000          .              1.00000     1581.08333-
   634  J7168     UL         1.00000         .                .              1.00000     3420.00000-
   635  W7168     BS          .            184.00000          .              1.00000        .
   636  A8168     LL          .              .                .              1.00000      781.26667
   637  G8168     LL          .              .                .              1.00000     2623.53333
   638  HL168     LL          .              .                .           1000.00000        5.16073
   639  W8168     LL          .            119.00000          .              1.00000      119.00000
   640  ES168     LL          .          24000.00000          .              1.00000    17129.68750
   641  OSN       LL          .             15.10000          .          50000.00000        1.80000
   642  USN       BS      2935.83333        13.30000-         .          50000.00000        .
   643  OSH       BS      3500.00000         8.80000          .           7000.00000        .
   644  USH       LL          .              5.20000-         .           7000.00000        3.60000
   645  OSPH      LL          .              6.40000-         .            840.00000         .30000
   646  USPH      BS       160.00000         6.70000          .            160.00000        .
```

Figure 2.3-1 (continued) Sample portion of one optimum schedule, showing the status of nuclear and hydroelectric quotas for the end of the week.

```
NUMBER .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.

  647  A1064    IV      1.00000       8552.00000          .            1.00000      10628.00000-
  648  A2064    IV      1.00000       4052.00000          .            1.00000       4118.00000-
  649  A3064    IV      1.00000       4300.00000          .            1.00000       7070.00000-
  650  A4064    IV      1.00000       3380.00000          .            1.00000       4200.00000-
  651  A5064    IV      1.00000      17960.00000          .            1.00000      13580.00000-
  652  B5064    IV       .            8420.00000          .            1.00000           .
  653  A6064    IV      1.00000        507.00000          .            1.00000      34729.00000-
  654  A7064    IV      1.00000        452.00000          .            1.00000       6027.00000-
  655  A1072    IV      1.00000       8480.00000          .            1.00000        284.00000-
  656  A2072    EQ       .            4077.00000          .             .              85.00000
  657  A3072    IV      1.00000       4199.00000          .            1.00000       1007.00000
  658  A4072    IV      1.00000       3342.00000          .            1.00000       1214.00000
  659  A5072    IV      1.00000      17663.00000          .            1.00000       4883.00000
  660  B5072    IV       .            8500.00000          .            1.00000           .
  661  A6072    IV      1.00000        471.00000          .            1.00000           .
  662  A7072    IV      1.00000        258.00000          .            1.00000         41.00000-
  663  A1080    IV      1.00000       7163.00000          .            1.00000           .
  664  A2080    EQ       .            3647.00000          .             .            4406.00000-
  665  A3080    IV       .            4281.00000          .            1.00000           .
  666  A4080    IV       .            3421.00000          .            1.00000       1143.00000
  667  A5080    IV       .           17768.00000          .            1.00000           .
  668  B5080    IV       .            8740.00000          .            1.00000       4826.00000
  669  A6080    IV      1.00000        389.00000          .            1.00000        159.00000-
  670  A7080    IV      1.00000        245.00000          .            1.00000           .
  671  A1088    IV      1.00000       7522.00000          .            1.00000      14736.00000-
  672  A2088    IV      1.00000       3689.00000          .            1.00000           .
  673  A3088    IV      1.00000       4032.00000          .            1.00000       6093.00000-
  674  A4088    IV      1.00000       3251.00000          .            1.00000       4075.00000-
  675  A5088    IV      1.00000      17634.00000          .            1.00000      12364.00000-
  676  B5088    IV       .            8520.00000          .            1.00000           .
  677  A6088    IV      1.00000        547.00000          .            1.00000      39058.00000-
  678  A7088    IV      1.00000        244.00000          .            1.00000       6209.00000-
  679  A1096    IV      1.00000       8040.00000          .            1.00000           .
  680  A2096    IV      1.00000       3966.00000          .            1.00000           .
  681  A3096    IV      1.00000       4106.00000          .            1.00000        914.00000
  682  A4096    IV       .            3377.00000          .            1.00000           .
  683  A5096    IV      1.00000      17621.00000          .            1.00000       4611.00000
  684  B5096    IV       .            8270.00000          .            1.00000           .
  685  A6096    IV      1.00000        544.00000          .            1.00000        485.00000
  686  A7096    IV      1.00000        198.00000          .            1.00000          2.00000-
  687  A1104    IV      1.00000       7696.00000          .            1.00000       1098.00000-
  688  A2104    IV      1.00000       3674.00000          .            1.00000           .
  689  A3104    IV       .            4201.00000          .            1.00000        824.00000
  690  A4104    IV       .            3274.00000          .            1.00000           .
  691  A5104    IV       .           16438.00000          .            1.00000       2826.00000
  692  B5104    IV       .            8070.00000          .            1.00000           .
  693  A6104    IV      1.00000        512.00000          .            1.00000           .
  694  A7104    IV      1.00000        324.00000          .            1.00000           .
  695  A1112    IV      1.00000       8720.00000          .            1.00000           .
  696  A2112    IV      1.00000       3500.00000          .            1.00000           .
  697  A3112    IV       .            4233.00000          .            1.00000           .
  698  A4112    IV       .            3332.00000          .            1.00000           .
  699  A5112    IV      1.00000      17362.00000          .            1.00000       4052.00000
  700  B5112    IV       .            7970.00000          .            1.00000           .
  701  A6112    IV      1.00000        448.00000          .            1.00000           .
  702  A7112    IV      1.00000        200.00000          .            1.00000           .
```

Figure 2.3-1 (continued) Sample portion of one optimum schedule, showing the values of the decision variables for which the third decision field was responsible.

NODE	13	20	23
FUNCTIONAL	599643.9740	600989.9740	599308.9740
ESTIMATION	INTEGER	INTEGER	INTEGER
647= A1064	1.0000	1.0000	1.0000
648= A2064	1.0000	1.0000	1.0000
649= A3064	1.0000	1.0000	1.0000
650= A4064	1.0000	1.0000	1.0000
651= A5064	1.0000	1.0000	1.0000
652= B5064	.	.	.
653= A6064	1.0000	1.0000	1.0000
654= A7064	1.0000	1.0000	1.0000
655= A1072	1.0000	1.0000	1.0000
657= A3072	1.0000	1.0000	1.0000
658= A4072	1.0000	.	1.0000
659= A5072	1.0000	1.0000	1.0000
660= B5072	.	.	.
661= A6072	1.0000	1.0000	1.0000
662= A7072	1.0000	1.0000	1.0000
663= A1080	1.0000	1.0000	1.0000
665= A3080	.	.	.
666= A4080	.	.	.
667= A5080	.	.	.
668= B5080	.	.	.
669= A6080	1.0000	1.0000	1.0000
670= A7080	1.0000	1.0000	1.0000
671= A1088	1.0000	1.0000	1.0000
672= A2088	1.0000	1.0000	1.0000
673= A3088	1.0000	1.0000	1.0000
674= A4088	1.0000	1.0000	1.0000
675= A5088	1.0000	1.0000	1.0000
676= B5088	.	.	.
677= A6088	1.0000	1.0000	1.0000
678= A7088	1.0000	1.0000	1.0000
679= A1096	1.0000	1.0000	1.0000
680= A2096	1.0000	1.0000	1.0000
681= A3096	.	.	1.0000
682= A4096	1.0000	1.0000	.
683= A5096	1.0000	1.0000	1.0000
684= B5096	.	.	.
685= A6096	1.0000	1.0000	1.0000
686= A7096	1.0000	1.0000	1.0000
687= A1104	1.0000	1.0000	1.0000
688= A2104	1.0000	1.0000	1.0000
689= A3104	.	.	.
690= A4104	.	.	.
691= A5104	.	.	.
692= B5104	.	.	.
693= A6104	1.0000	1.0000	1.0000
694= A7104	1.0000	1.0000	1.0000
695= A1112	1.0000	1.0000	1.0000
696= A2112	1.0000	1.0000	1.0000
697= A3112	.	.	.
698= A4112	.	.	.
699= A5112	1.0000	1.0000	1.0000
700= B5112	.	.	.
701= A6112	1.0000	1.0000	1.0000
702= A7112	1.0000	1.0000	1.0000

Figure 2.3-2 The three completed schedules obtained for the problem of minimizing dollar + water + air pollution levels for the system under standard reliability requirements, node 23 is the best of these three schedules as indicated by the values of their respective cost functionals.

NODE	24 P	2	6	14 P	16	21 P
FUNCTIONAL	599301.4155	607169.0469	600621.0469	599791.2870	599435.5191	601137.2870
ESTIMATION	599312.	607606.	601058.	599945.	599883.	601291.
647= A1064	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
648= A2064	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
649= A3064	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
650= A4064	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
651= A5064	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
652= B5064	.	.	.	.	.	.
653= A6064	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
654= A7064	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
655= A1072	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
657= A3072	1.0000	1.0000	.	1.0000	1.0000	1.0000
658= A4072	1.0000	1.0000	1.0000	1.0000	.	.
659= A5072	1.0000	.	1.0000	1.0000	1.0000	1.0000
660= B5072	.	.	.	.	.	.
661= A6072	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
662= A7072	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
663= A1080	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
665= A3080	.	.	.	.	.	.
666= A4080	.	.	.	.	.	.
667= A5080	.	.	.	.	.	.
668= B5080	.	.	.	.	.	.
669= A6080	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
670= A7080	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
671= A1088	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
672= A2088	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
673= A3088	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
674= A4088	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
675= A5088	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
676= B5088	.	.	.	.	.	.
677= A6088	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
678= A7088	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
679= A1096	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
680= A2096	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
681= A3096	1.0000	1.0000	1.0000	.	1.0000	.
682= A4096	.	1.0000	1.0000	1.0000	.	1.0000
683= A5096	1.0000	.3854	.3854	1.0000	1.0000	1.0000
684= B5096	.	.	.	.	.	.
685= A6096	.9089	1.0000	1.0000	.9486	.9089	.9486
686= A7096	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
687= A1104	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
688= A2104	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
689= A3104	.	.	.	.	.	.
690= A4104	.	.	.	.	.	.
691= A5104	.	.	.	.	.	.
692= B5104	.	.	.	.	.	.
693= A6104	.9089	1.0000	1.0000	.9486	.9089	.9486
694= A7104	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
695= A1112	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
696= A2112	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
697= A3112	.	1.0000	1.0000	.	1.0000	.
698= A4112	.	1.0000	1.0000	.	1.0000	.
699= A5112	1.0000	.1458	.1458	1.0000	.1458	1.0000
700= B5112	.	.	.	.	.	.
701= A6112	.9906	1.0000	1.0000	.9906	1.0000	.9906
702= A7112	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Figure 2.3-3 The remaining incomplete schedules still held for the system at the completion of the three complete schedules displayed in the previous figure.

2.4 Unit Commitment Scheduling Results

The plots and graphs in this section will be more or less self-explanatory. All of this data is contained in Appendix D.

2.4.1 Varying Economic-Environmental Strategies

Figure 2.4.1-1 represents the dollar costs versus water pollution impacts of the minimum dollar QD, minimum water pollution QW, and minimum dollar + water pollution QV schedules. This line then represents the set of all possible consequences of optimum dollar-water pollution strategies. Although there are only three points to show the shape of this curve it is almost exactly defined using the added information available. In particular, it is known that the slope of this curve = 1 at the point QV, and the curve must be concave[10] and contained within the projections of minimum dollar costs and minimum water pollution costs.

Each point in these curves is the result of the best of three near optimum schedules. To see what kind of variability[11] does exist among these schedules and the degenerated linear optimum schedule see Appendix E. It is reasonable to

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[10] It is assumed that these curves are relatively smooth due to the great number of variables and the relative closeness of these schedules to the actual linear optimums, which can be proven to have a connected concave shape.

[11] For an idea of the magnitude of this variability with respect to the plots presented, using the scale of figure 2.4.1-1 for example, the optimum linear solution and all of the computed schedules lie within 1/40th of an inch of each other.

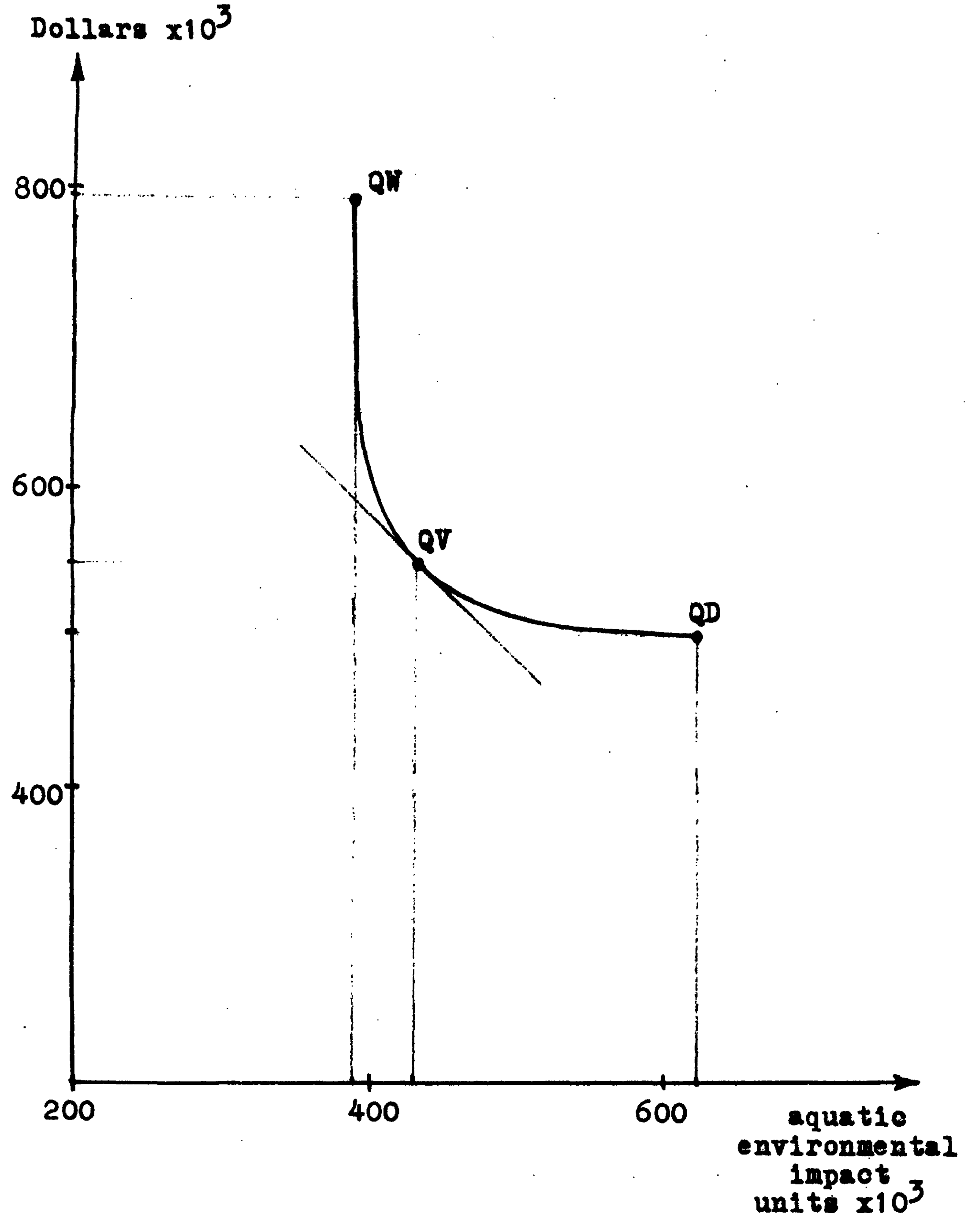

Figure 2.4.1-1 The tradeoff curve representing all possible optimum consequences of dollar and water pollution strategies at standard reliability.

assume that the points represented in these graphs are at the true optimum's positions One percentage difference in costs between the optimum linear schedules and the valid, integer schedules was about the maximum error. Thus, any large amount of work, particularly including simulations of hypothetical systems, could surely use pure linear programs if indeed this 1% error is about the magnitude which results for the particular system to be investigated.

Figure 2.4.1-2 displays the contribution of the various system components to these three schedules, the optimum dollar cost QD, water pollution minimum QW, and dollar + water pollution optimization QV.

Figure 2.4.1-3 represents the tradeoff curve for the minimum dollar QD, minimum dollar + air pollution + water pollution QT, and minimum air + water pollution QE schedules, and figure 2.4.1-4 shows this system component breakdown.

Figures 2.4.1-5 and 2.4.1-6 are the displays for the minimum dollar QD, minimum air pollution QA, and minimum dollar + air pollution QB schedules and strategies.

It is also possible to display these three transform curves, which have just been presented, all on one three dimensional plot, and this (using a little imagination) can be seen in figure 2.4.1-7. This surface should be visualized as a triangle which has been punched in, and which is actually quite flat on the bottom (making a strict dollar minimization, as is currently used, unwise).

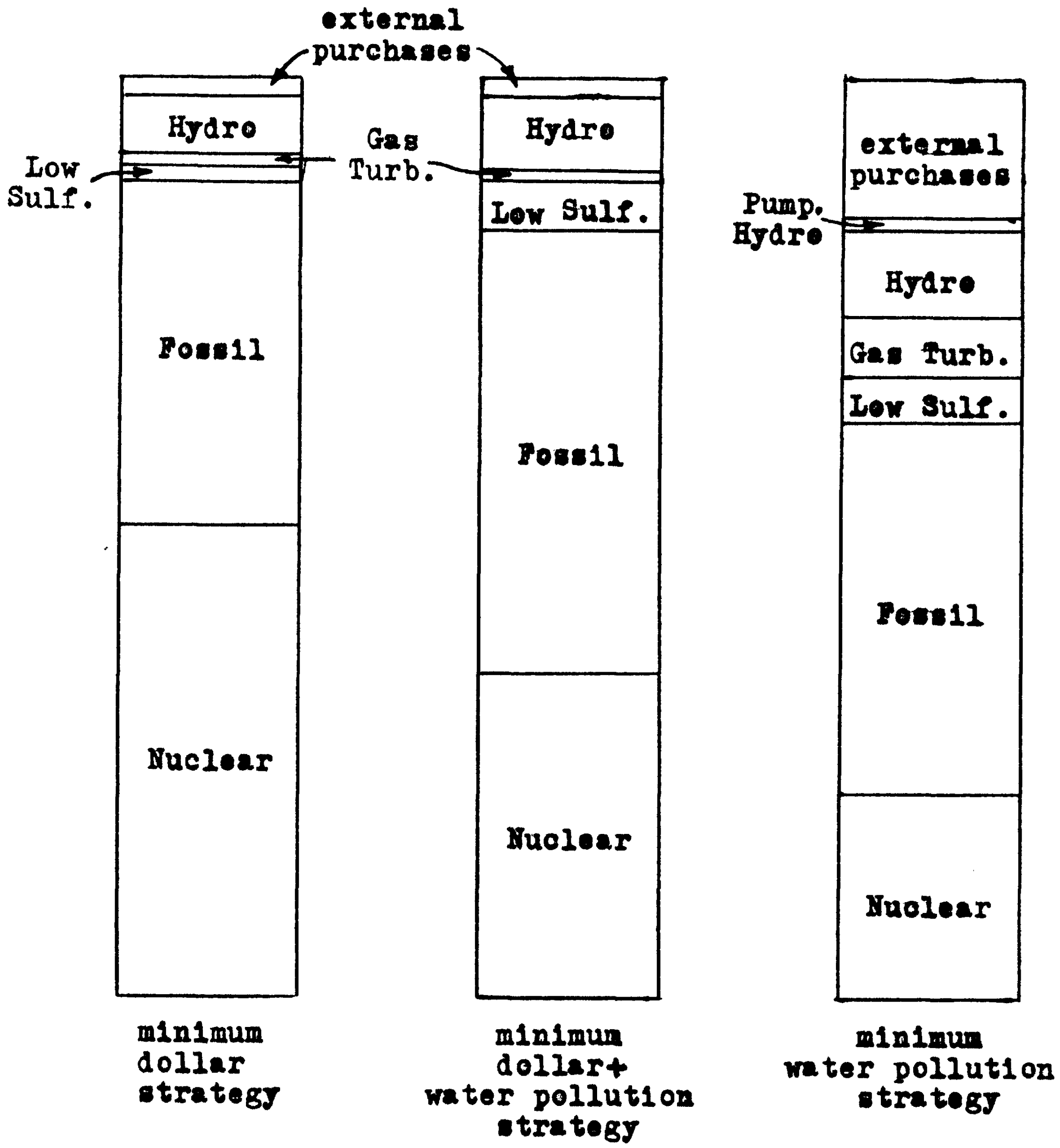

Figure 2.4.1-2 Contributions of the various system components in actual optimum schedules (standard reliability).

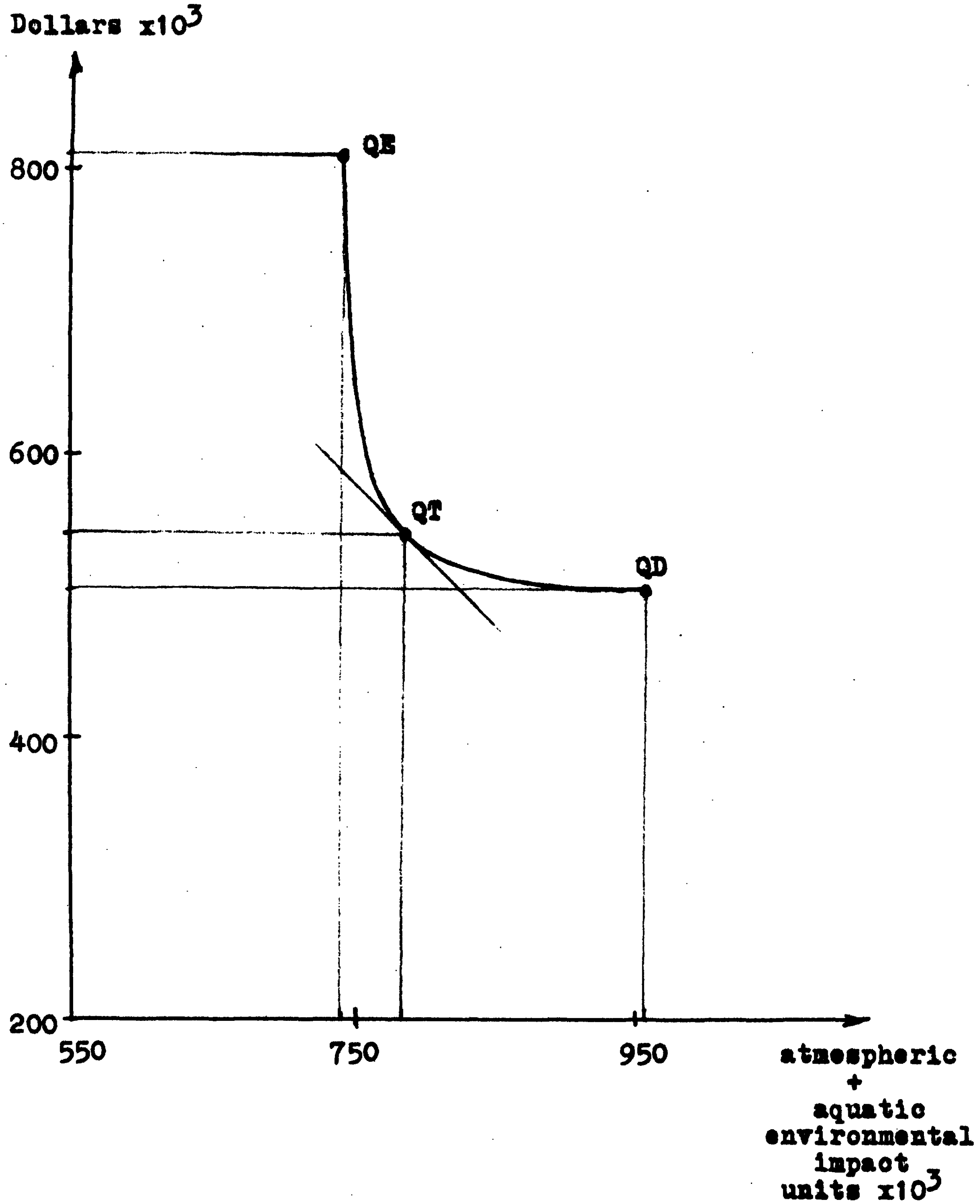

Figure 2.4.1-3 The tradeoff curve representing all possible optimum consequences of dollar and air+water pollution strategies at standard reliability.

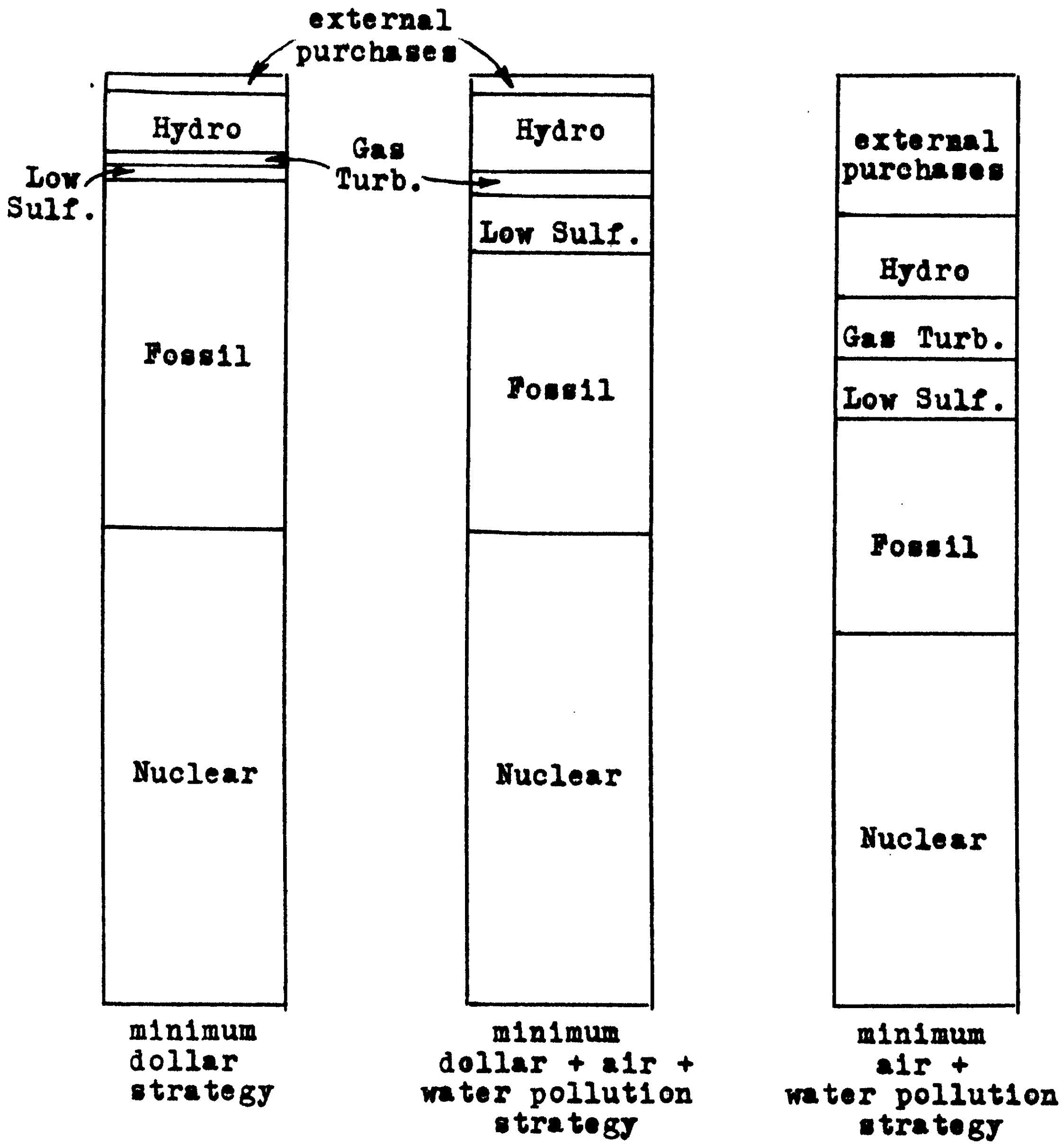

Figure 2.4.1-4 Contributions of the various system components in optimum schedules (standard reliability).

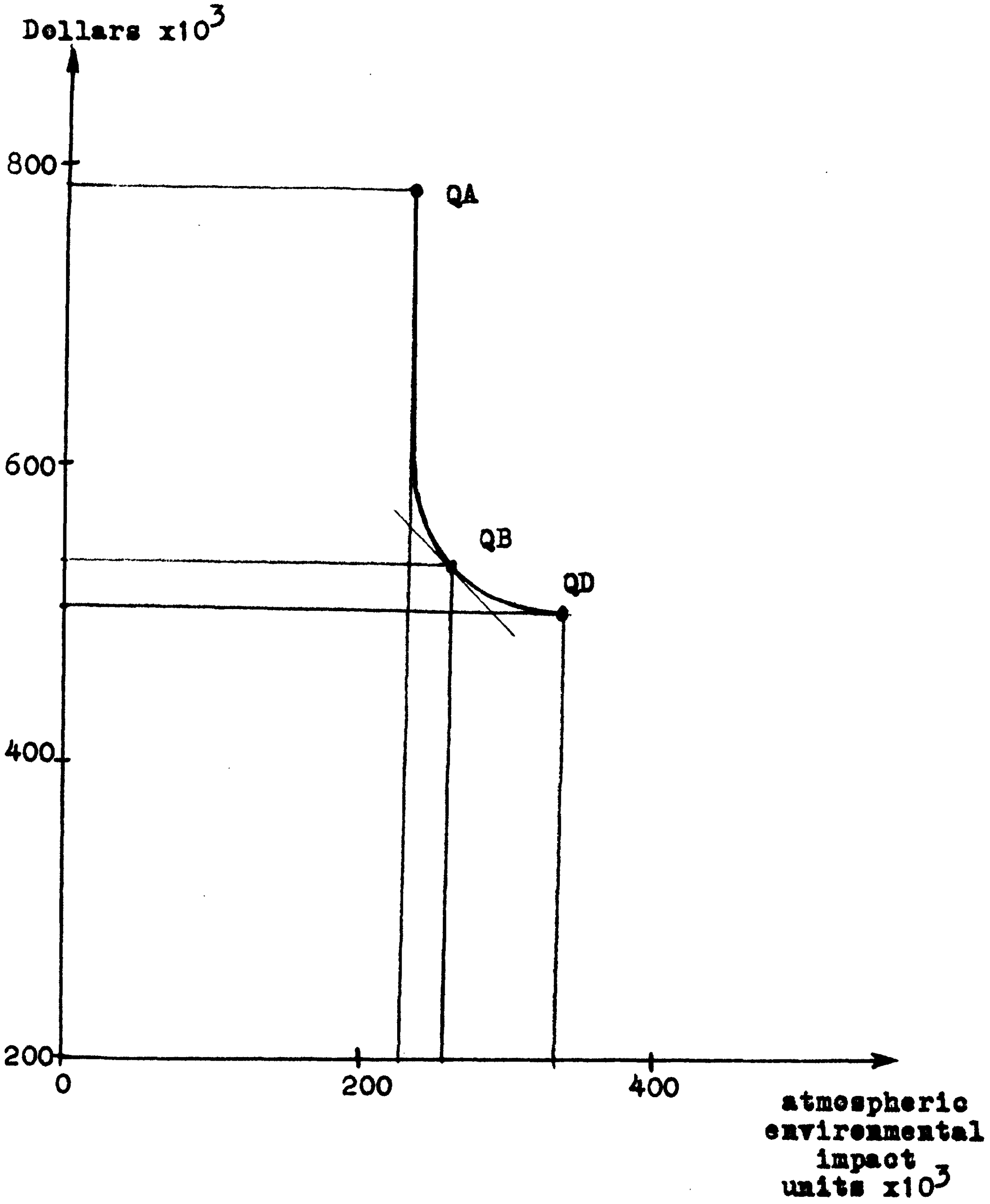

Figure 2.4.1-5 The tradeoff curve representing all possible optimum consequences of dollar cost and air pollution strategies at standard reliability.

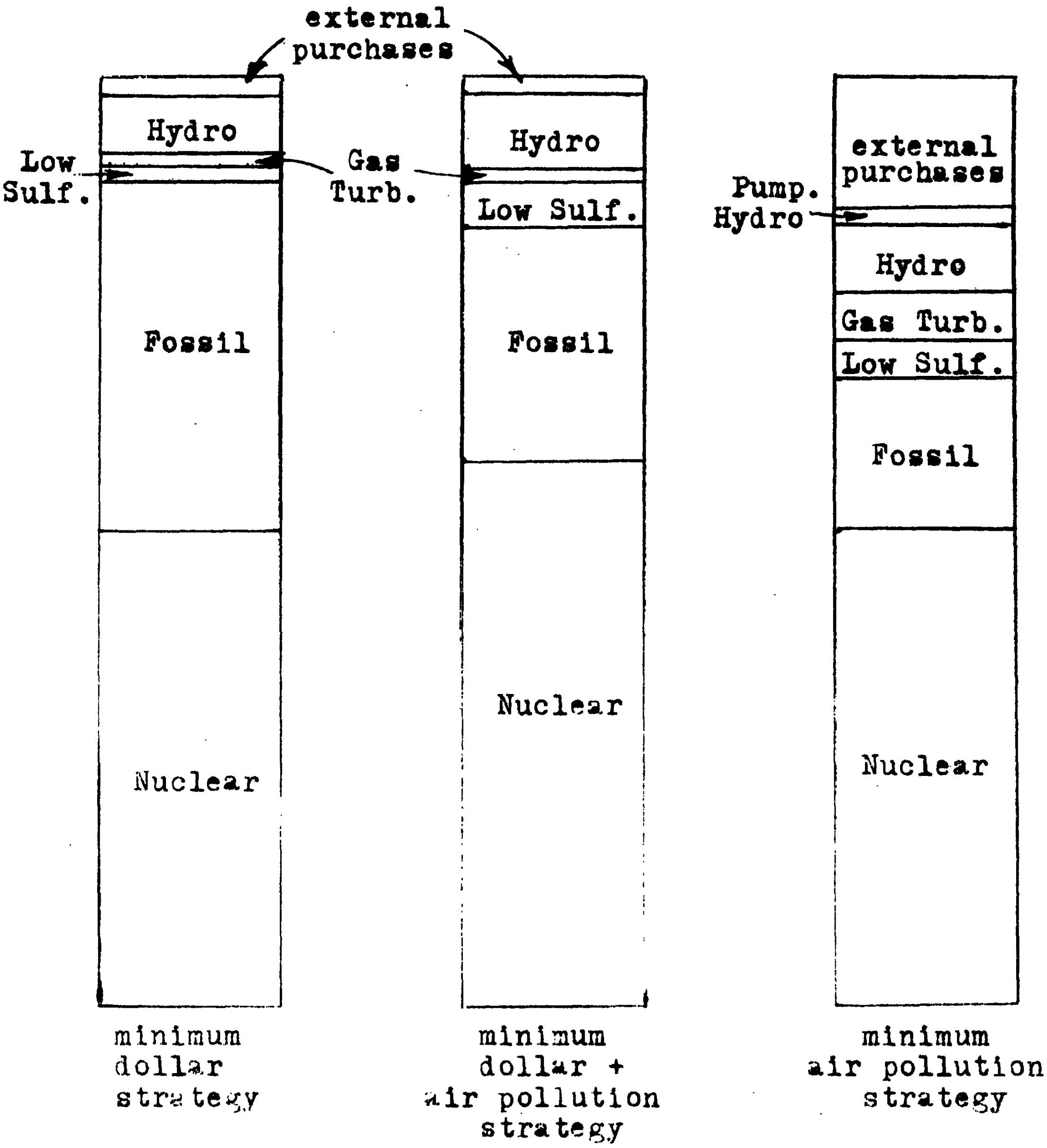

Figure 2.4.1-6 Contributions of the various system components in actual optimum schedules (standard reliability).

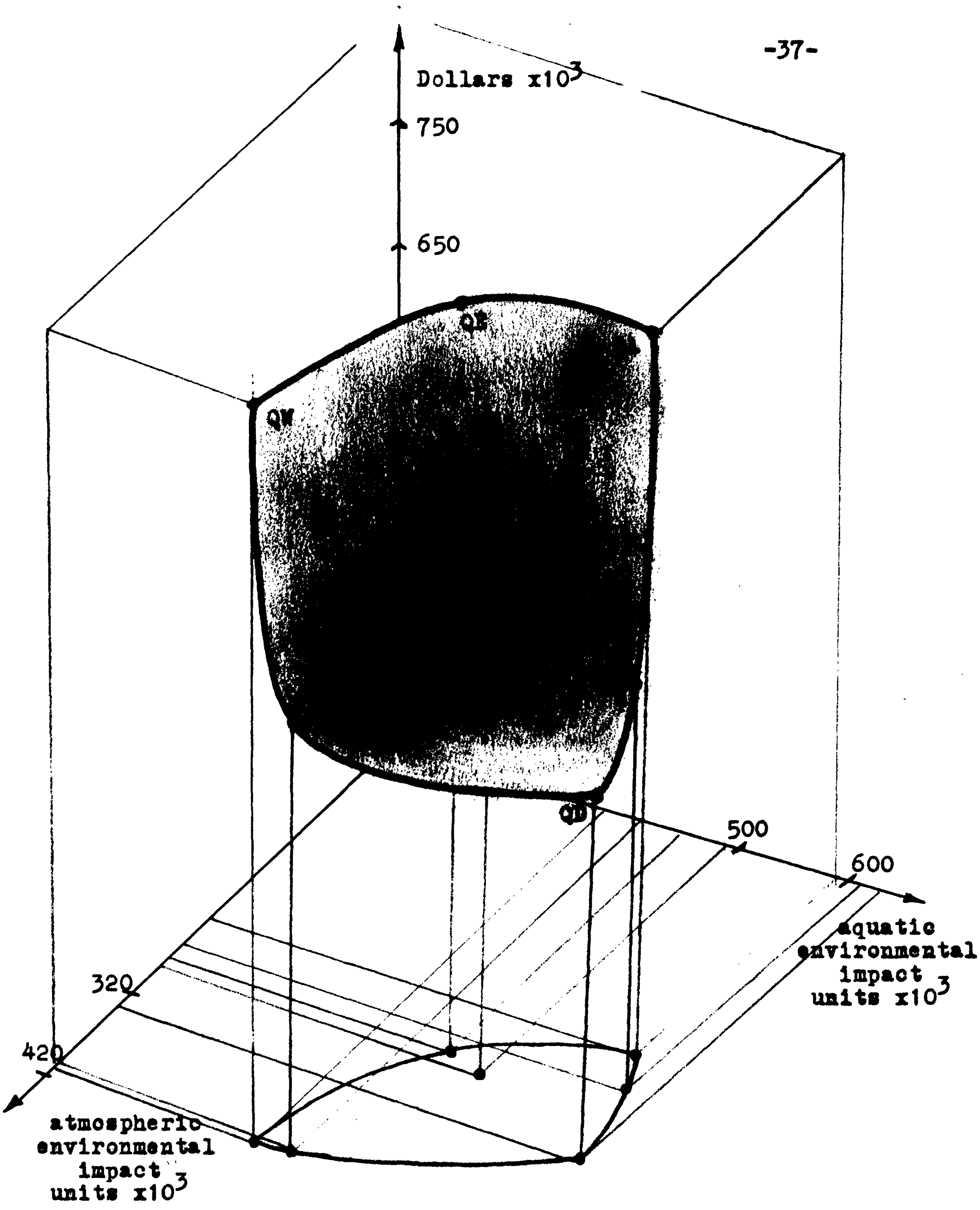

Figure 2.4.1-7 The transform surface associated with all optimum economic-environmental consequences (standard reliability)

2.4.2 Varying System Demand-Meeting Requirements

For each of the scheduling strategies explained in section 2.4.1, i.e. QD, QA, QW, QT, QE, QB, and QV it is also possible to parameterize the reliability requirements, that is, the load meeting probability, of the power system from low reliability, through standard reliability, to high reliability. These curves and bar graphs of system schedule consequences and system component contributions are contained in figures 2.4.2-1 through 2.4.2-10.

Here again it is possible, obviously, to take the entire transform surface of figure 2.4.1-7 and display the reliability parameterization as surfaces above (i.e. more costly for higher reliability requirements) and below (i.e. less costly for relaxed reliability requirements) that standard reliability tradeoff surface. This solid of all possible optimum consequences of economic-environmental-security strategies is represented in figure 2.4.2-11.

These tradeoff curves show generally that there is a great deal of 'flexibility' in this system for adapting to different scheduling strategies. Here, an 'inflexible' or unbending system would have a tradeoff surface which was a flat plane through the minimum dollar, minimum air pollution, and minimum water pollution points, so in effect one could choose from among the various types of consequences of system operation, but one would have no variation in the combined total of the consequences. On the other hand

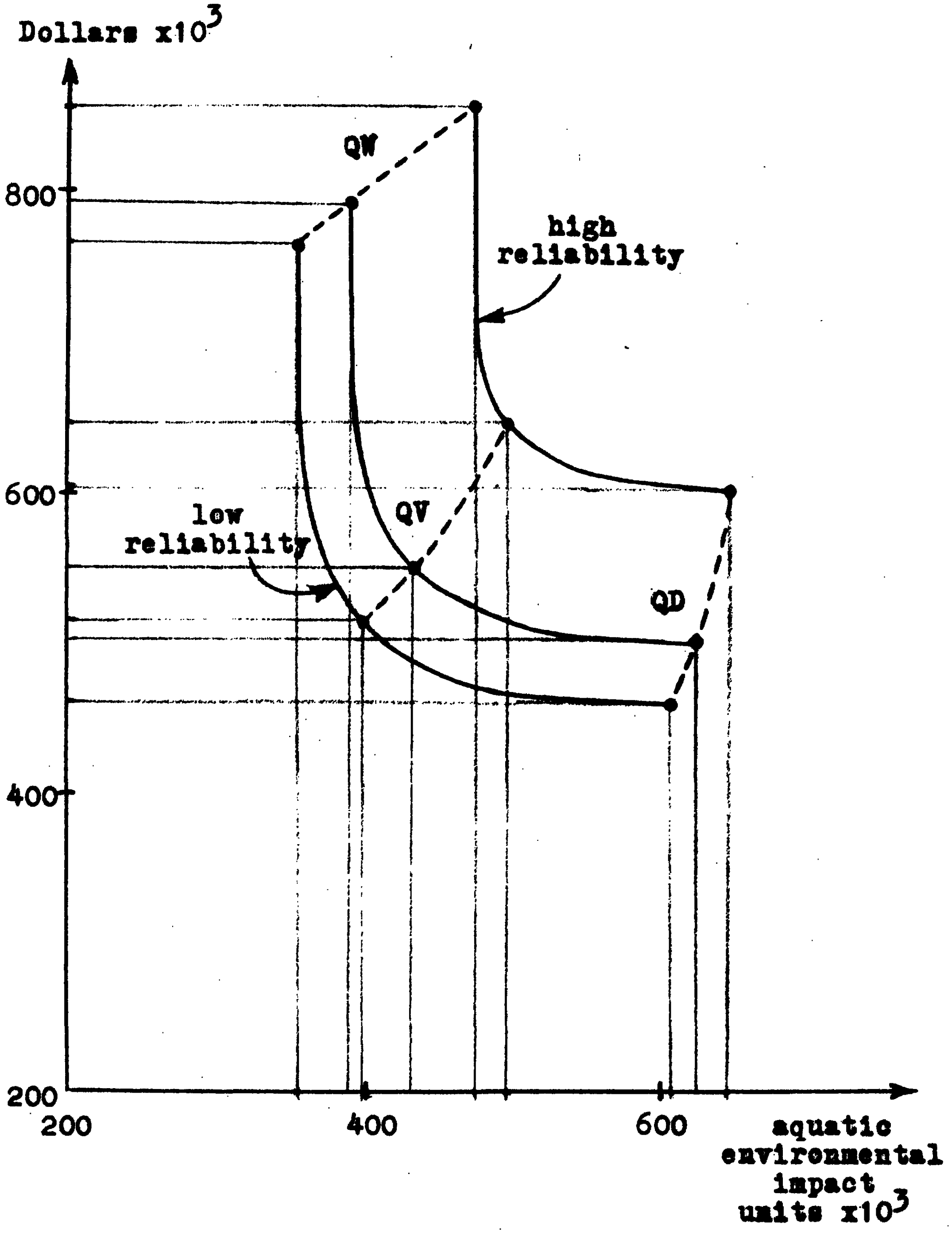

Figure 2.4.2-1 The three transform curves representing all possible consequences of optimum dollar-water pollution strategies at low, standard and high reliability levels.

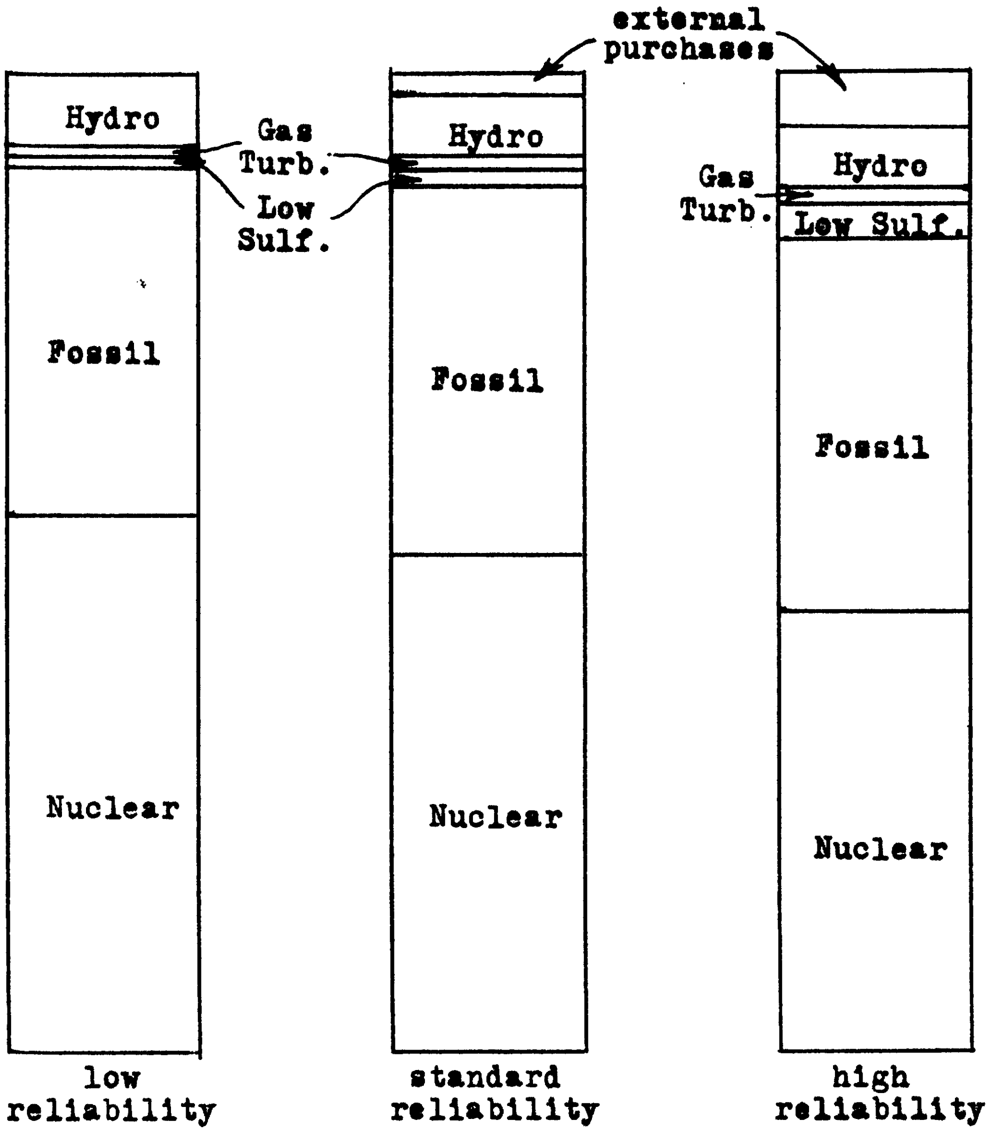

Figure 2.4.2-2 Contributions of the system generation components to the schedules which minimize the dollar cost for various reliability levels

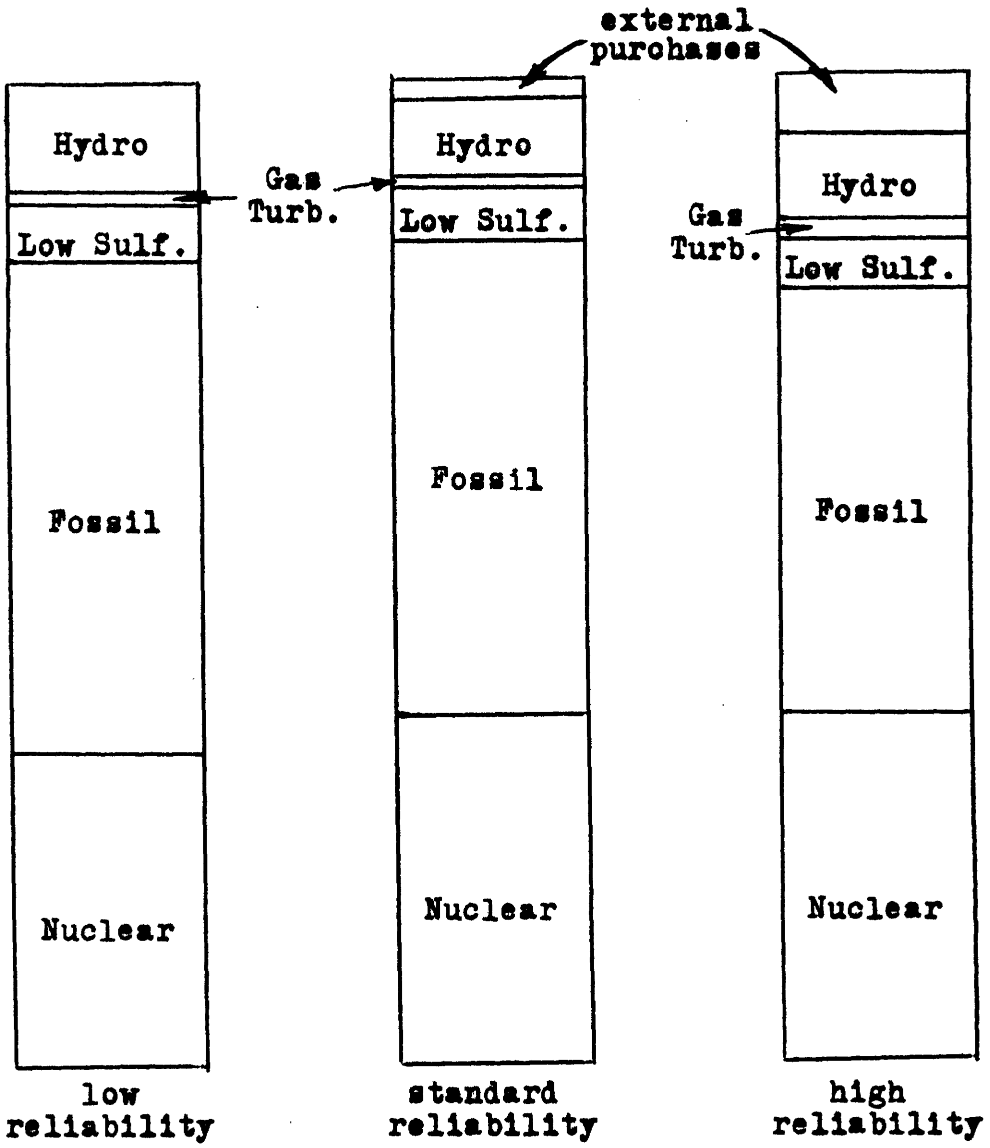

Figure 2.4.2-3 Contributions of system components to the schedules which minimize dollar + water pollution for various reliability levels

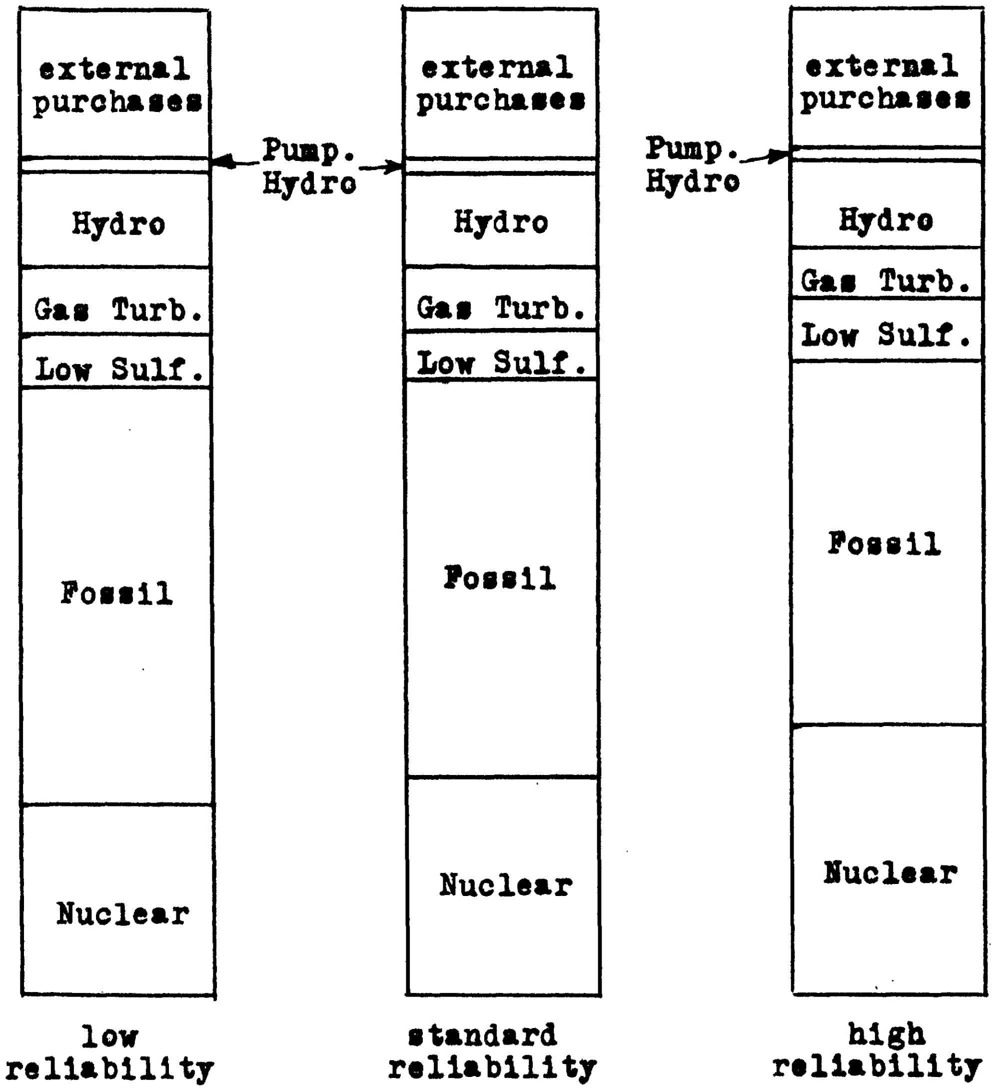

Figure 2.4.2-4 Contributions of system components in schedules optimizing water quality for various reliability levels.

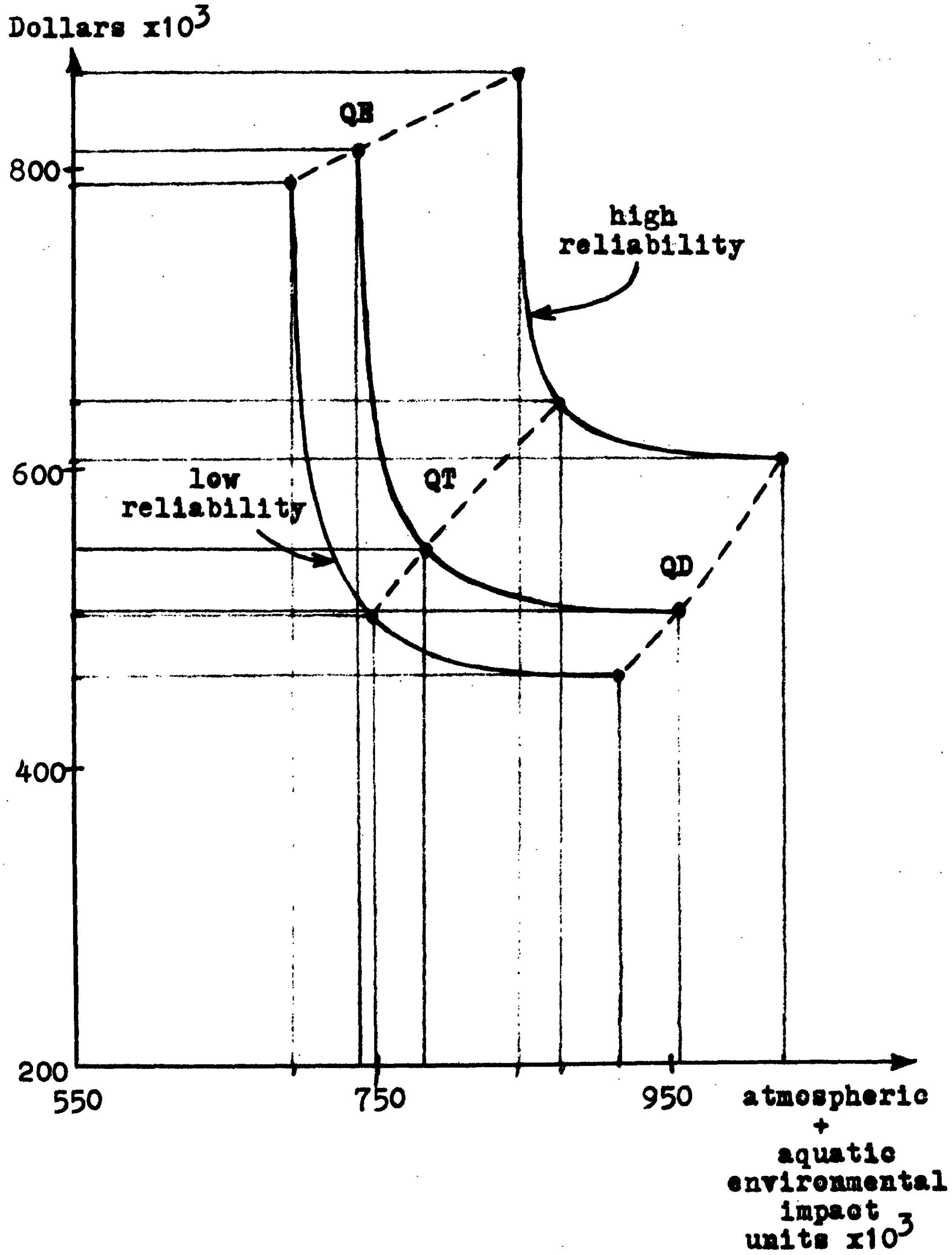

Figure 2.4.2-5 The three transform curves representing all possible consequences of optimum dollar-environmental (i.e. air+water pollution) strategies at low, standard and high reliability levels.

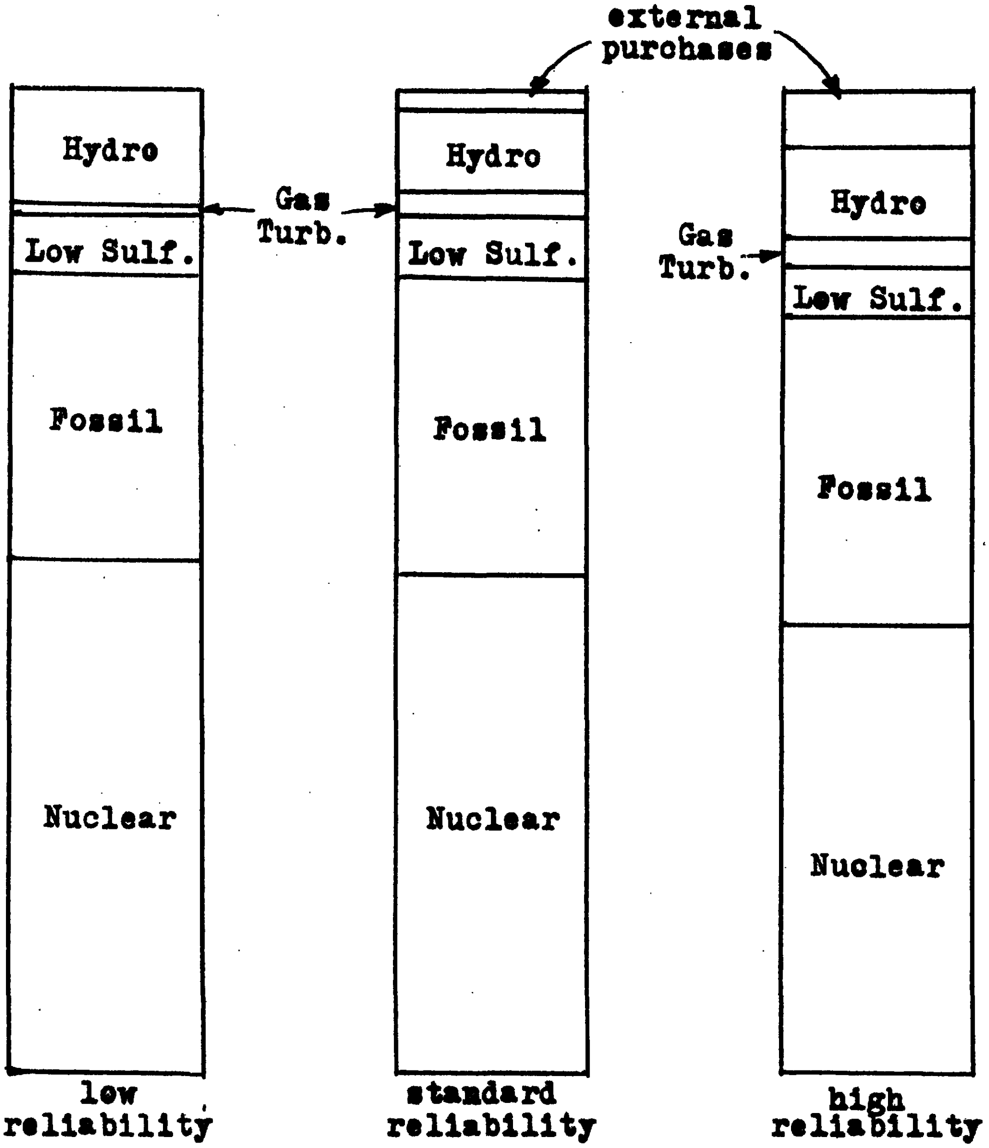

Figure 2.4.2-6 Contributions of system components to the optimum schedules which minimized dollar + water + air pollution for various reliability levels

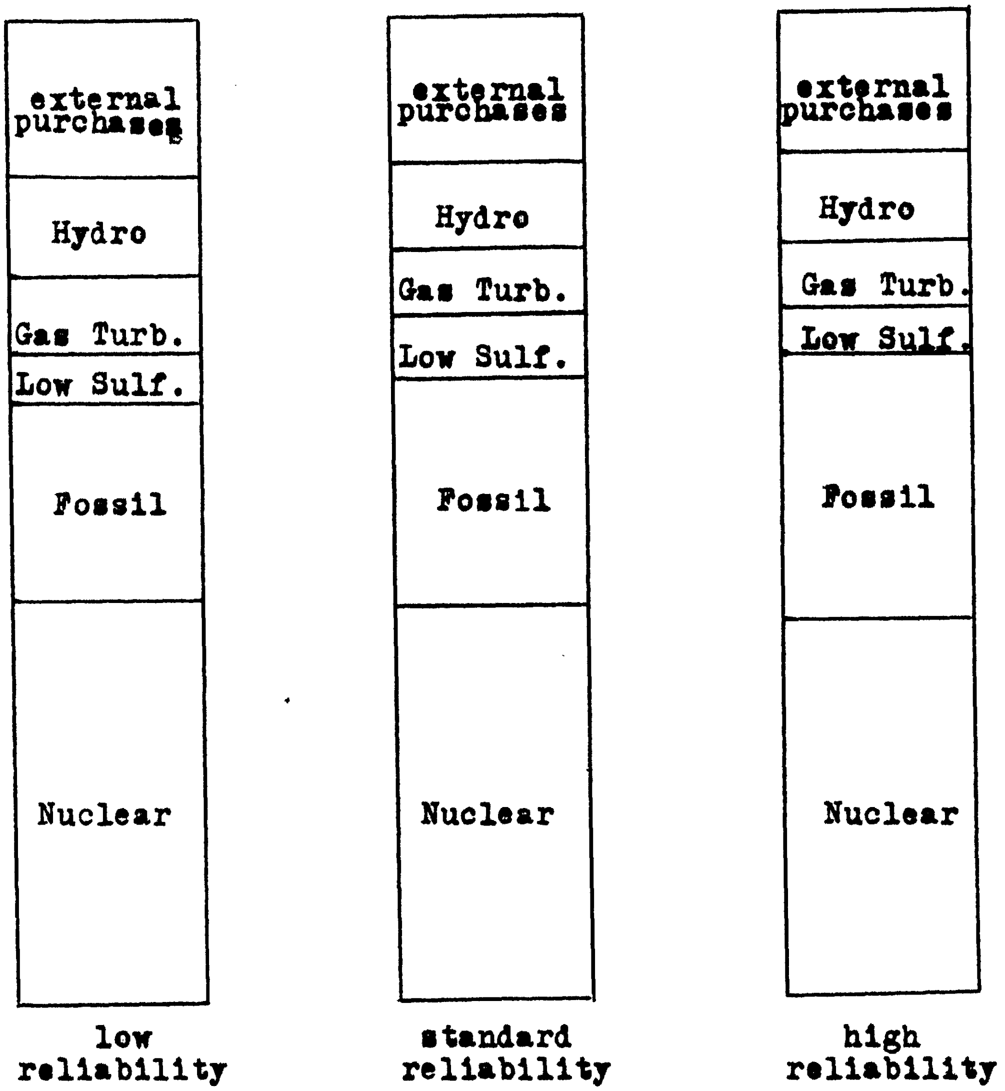

Figure 2.4.2-7 Contributions of system components to the schedules which minimize air + water pollution for various reliability levels

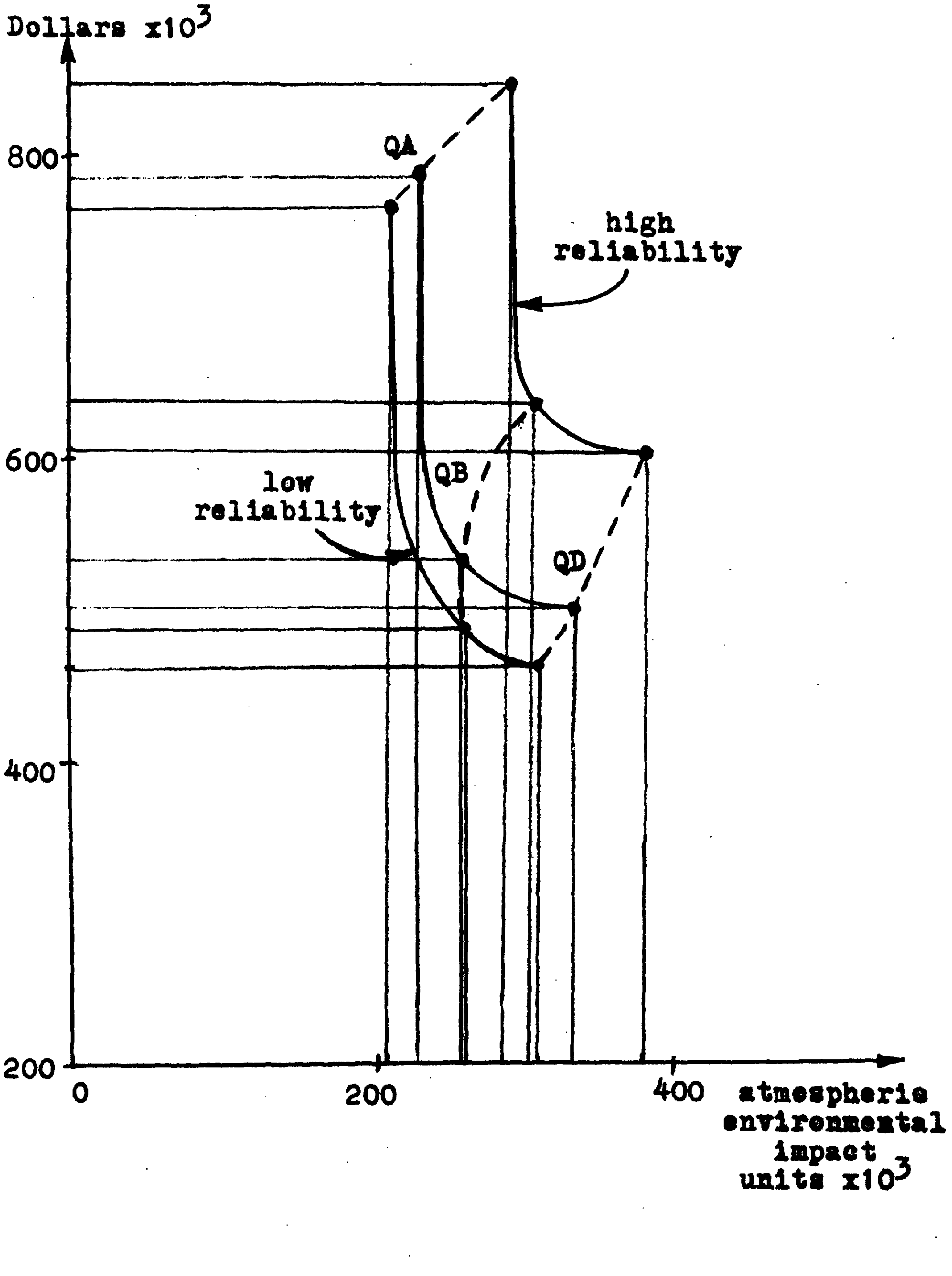

Figure 2.4.2-8 The three tradeoff curves representing all possible consequences of optimum dollar-air pollution strategies at low, standard and high reliability levels.

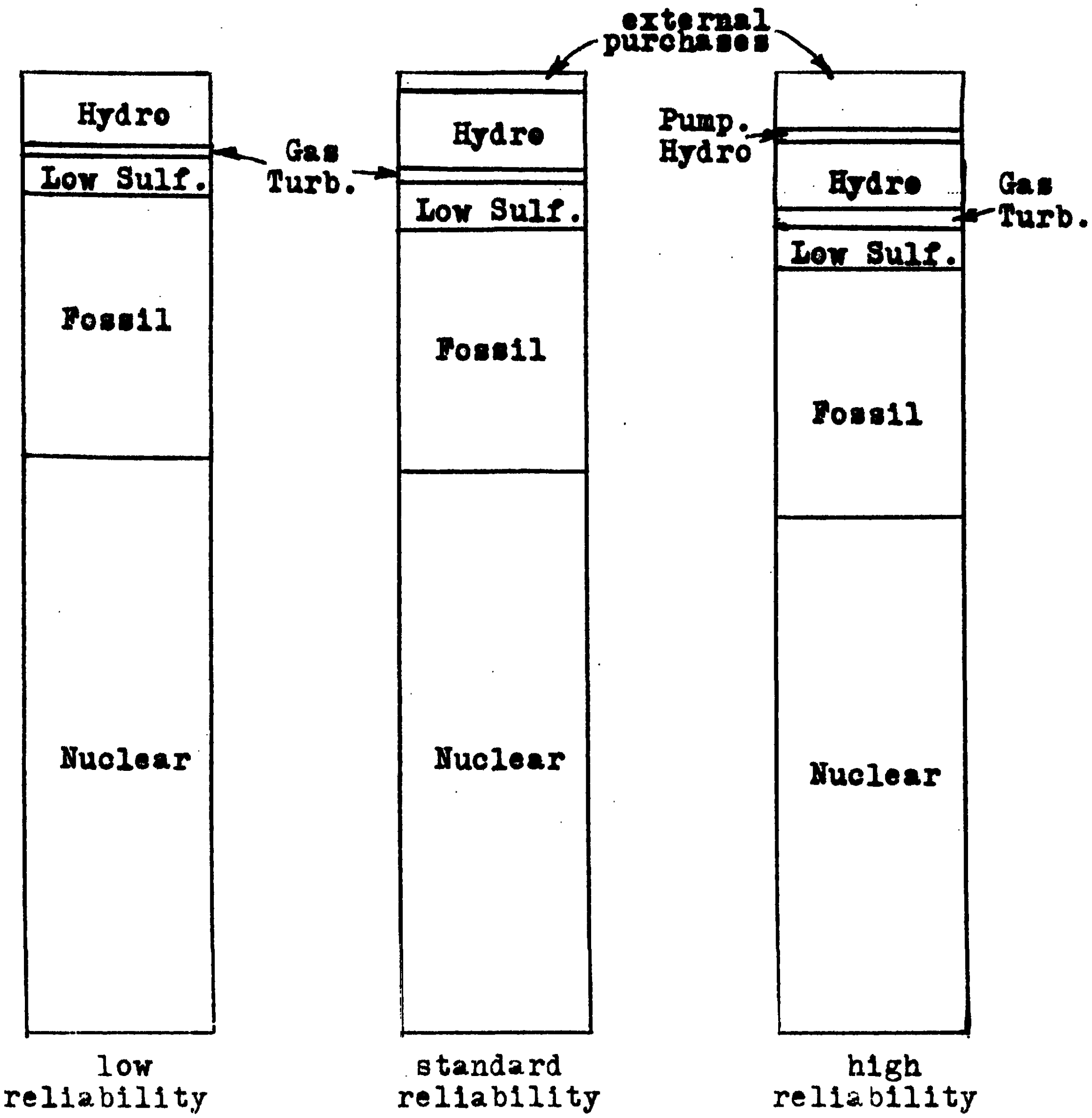

Figure 2.4.2-9 Contributions of system components to schedules minimizing dollar + **air** pollution for various reliability levels

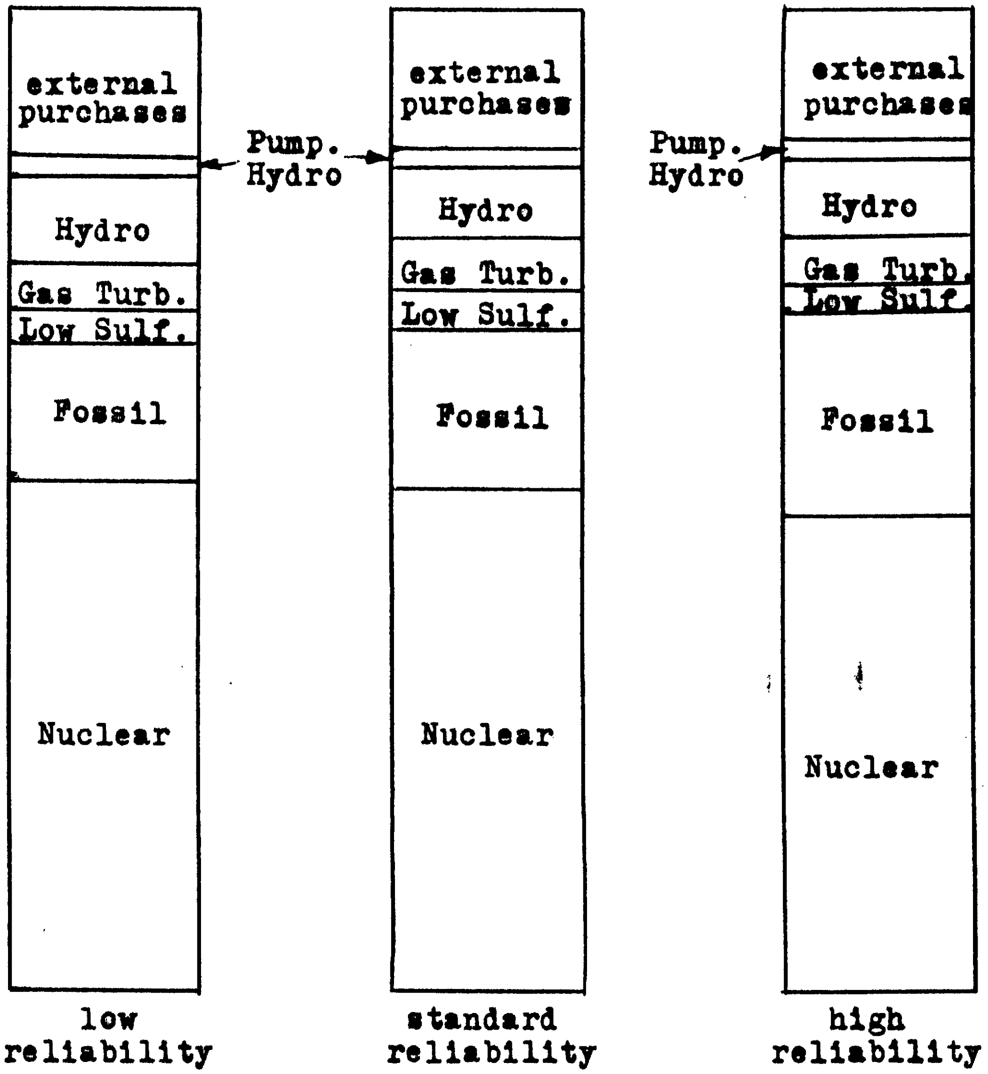

Figure 2.4.2-10 Contributions of the system components to the schedules which minimize air pollution for various reliability levels

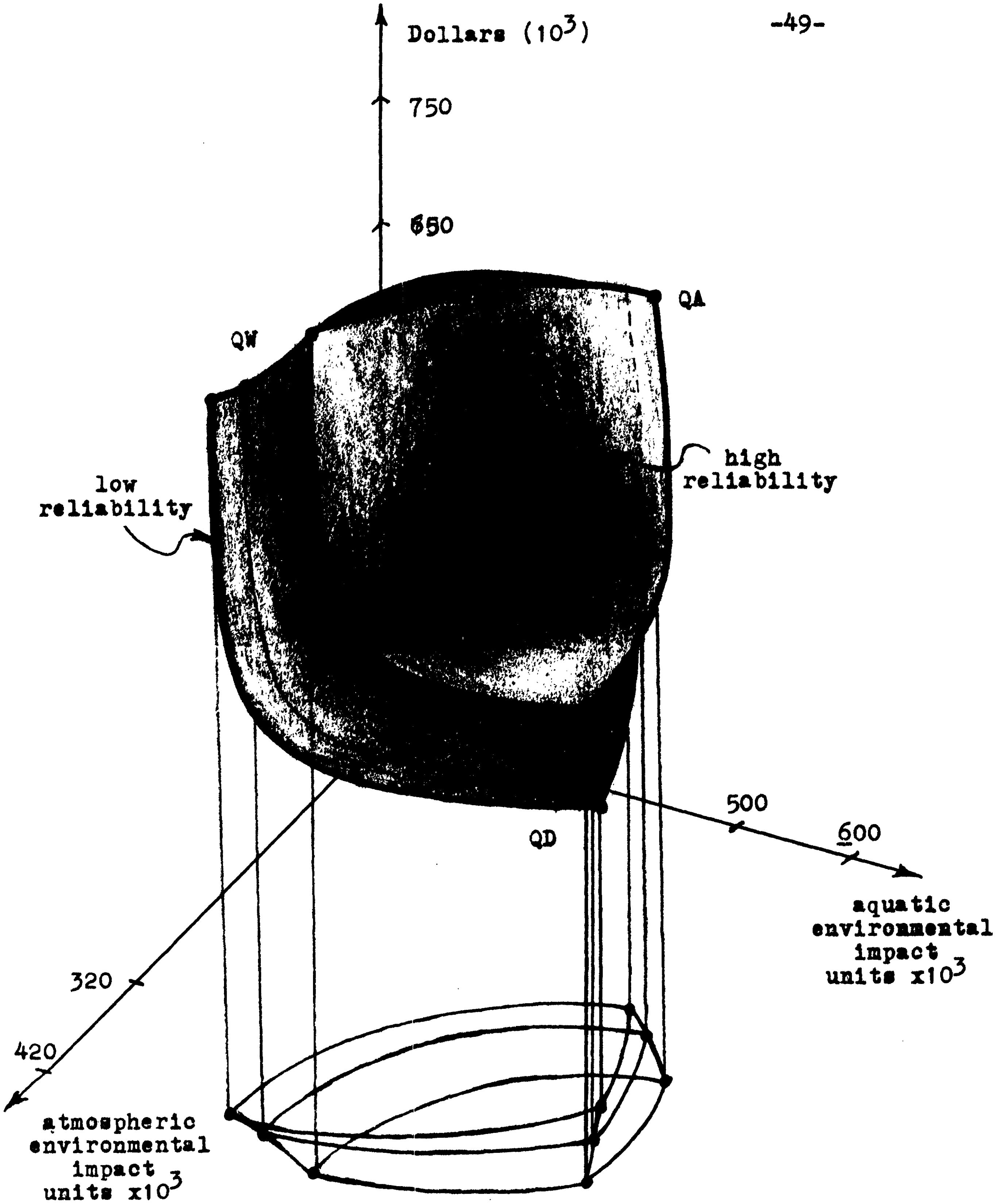

Figure 2.4.2-11 The solid tradeoff figure representing all possible optimum consequences of different economic-environmental-security strategies.

a one hundred percent 'flexibility' would allow operation at the 'ideal' point of simultaneously minimizing dollars, air and water pollution. This 100% flexible curve would be 'pushed in' so far that it would be like the corner of a cube. The sample system studied shows a scheduling surface 'flexibility' of approximately 65%, i.e. rather a deep pocket in that surface. This characteristic means that minimizing dollars, air or water pollution alone or even in pairs is probably not a wise criterion because large gains in the unconsidered consequences could be made for very slight increases in the undesirability of the measures used.

Note: The word 'reliability' has been used very loosely in this chapter. Strictly speaking a higher reliability requirement should increase the spinning reserve, but not the actual demand for power. In this chapter the power demand was increased also, and thus the cost of meeting this higher demand also shows up in the consequences. What is actually represented here is a measure of the flexibility of the system with respect to meeting demand changes, that is, the resultant consequences of meeting higher of lower demands for power. The purer consequence of changes in reliability levels can be getten by subtracting the incremental costs of the extra power multiplied by the amount of additional demand met.

3. Transform Surfaces for Maintenance Schedules

This sample system will be only briefly described. An exact system description can be found in reference (5) on page 102, and the exact data used is displayed in Appendix C.

3.1 Description of Sample System

This is a twelve power plant system scheduled over an entire 39 week period. The components of this system are fossil plants: plant 1 of 225 megawatts, plant 2 of 125 megawatts, plant 3 of 150 megawatts, and plant 4 of 350 megawatts. There are two nuclear facilities, plant 5 of 550 megawatts and plant 6 of 600 megawatts. Plants 8 and 9 are 100 megawatt hydro stations. Plant 7 is a 75 megawatt pumped storage facility. There are three gas turbines: plants10 and 12 both of 85 megawatts, and plant 11 of 100 megawatts.

There are a number of interregional power buy and sell contract decisions to be settled by the scheduler, and there are many opportunities set up for possible extended shutdowns of various facilities for dollar and/or environmental gains.

3.2 Maintenance and Production Scheduling Results

The following are the results of the economic-environmental scheduling procedure. Exact data used for these graphs is contained in Appendix D.

The negative sign on some of the environmental axes results from the procedure of rewarding plants for being shut down, rather than the identical (complimentary) problem of penalizing the plants for operating.

3.2.1 Optimum Schedules

The schedules in figure 3.2.1-1 represent the seven optimum schedules which resulted from the maintenance scheduling mechanism. These displays do not, however, includedany of the weakly quotas, plant shutdowns or variable power sales which are also part of the maintenance and production schedule.[12]

3.2.2 Transform Surface of All Optimum Schedules

Figure 3.2.2-1 represents the dollar costs versus water pollution impacts of the minimum dollar QD, minimum water pollution QW, and minimum dollar + water pollution QV schedules. This line, then, represents the set of all possible consequences of optimum dollar-water pollution strategies. The point labelled X in these graphs represents the first feasible solution found by the computation process, and, thus, is a measure of the quality of a non-objective function 'fill-in-the-blank' scheduling technique such as is now used for the maintenance and production scheduling procedure.

---

[12] Persons interested in more detail from the optimum schedules may contact the author for a full set of data.

Unit	Week	QD	QV	QW	QE	QT	QB	QA
1	1	0	0	0	0	0	0	0
1	2	1	1	1	1	1	1	1
1	3	0	0	0	0	0	0	0
8	4	0	0	1	0	0	0	0
4	1	0	0	0	0	0	0	0
4	6	1	1	1	1	1	1	1
Buy contract	6	1	1	1	1	1	1	1
2	6	0	0	0	0	0	0	0
2	8	0	0	0	0	0	0	0
2	10	1	0	1	0	1	1	1
Sell	10	0	0	0	0	0	0	0
7	6	0	0	0	0	0	0	0
7	8	1	1	1	1	1	1	1
7	10	0	0	0	0	0	0	0
11	8	0	0	0	0	0	0	0
11	10	0	0	0	0	0	0	0
11	12	0	0	0	0	0	0	1
11	14	1	1	1	1	1	1	0
11	16	0	0	0	0	0	0	0
Buy	14	0	0	1	1	0	0	1
Buy	16	1	1	1	1	1	1	1
5	16	1	1	1	1	1	1	1
5	18	0	0	0	0	0	0	0
5	20	0	0	0	0	0	0	0
6	20	1	1	1	1	1	1	1
6	22	0	0	0	0	0	0	0
6	24	0	0	0	0	0	0	0
10	22	1	1	1	1	1	0	1
10	24	0	0	0	0	0	1	0
9	24	1	1	1	1	1	0	1
9	27	0	0	0	0	0	1	0
Sell	24	1	0	0	0	0	1	0
3	22	0	0	0	0	0	0	0
3	27	0	1	1	0	1	1	0
3	30	1	0	0	1	0	0	1
3	33	0	0	0	0	0	0	0
Sell	27	0	0	0	0	0	0	0
Sell	30	1	0	0	0	0	0	0
4	27	1	0	0	1	0	0	1
4	30	0	1	1	0	1	1	0
4	33	0	0	0	0	0	0	0
4	36	0	0	0	0	0	0	0
12	27	0	1	1	0	1	0	0
12	30	1	0	0	0	0	0	0
12	33	0	0	0	1	0	0	1
12	36	0	0	0	0	0	1	0

Figure 3.2.1-1 Maintenance decisions made for optimum schedules with different quality measures, 1 = out for maintenance, 0 = not out, 1 = power interchange contract accepted, 0 = rejected.

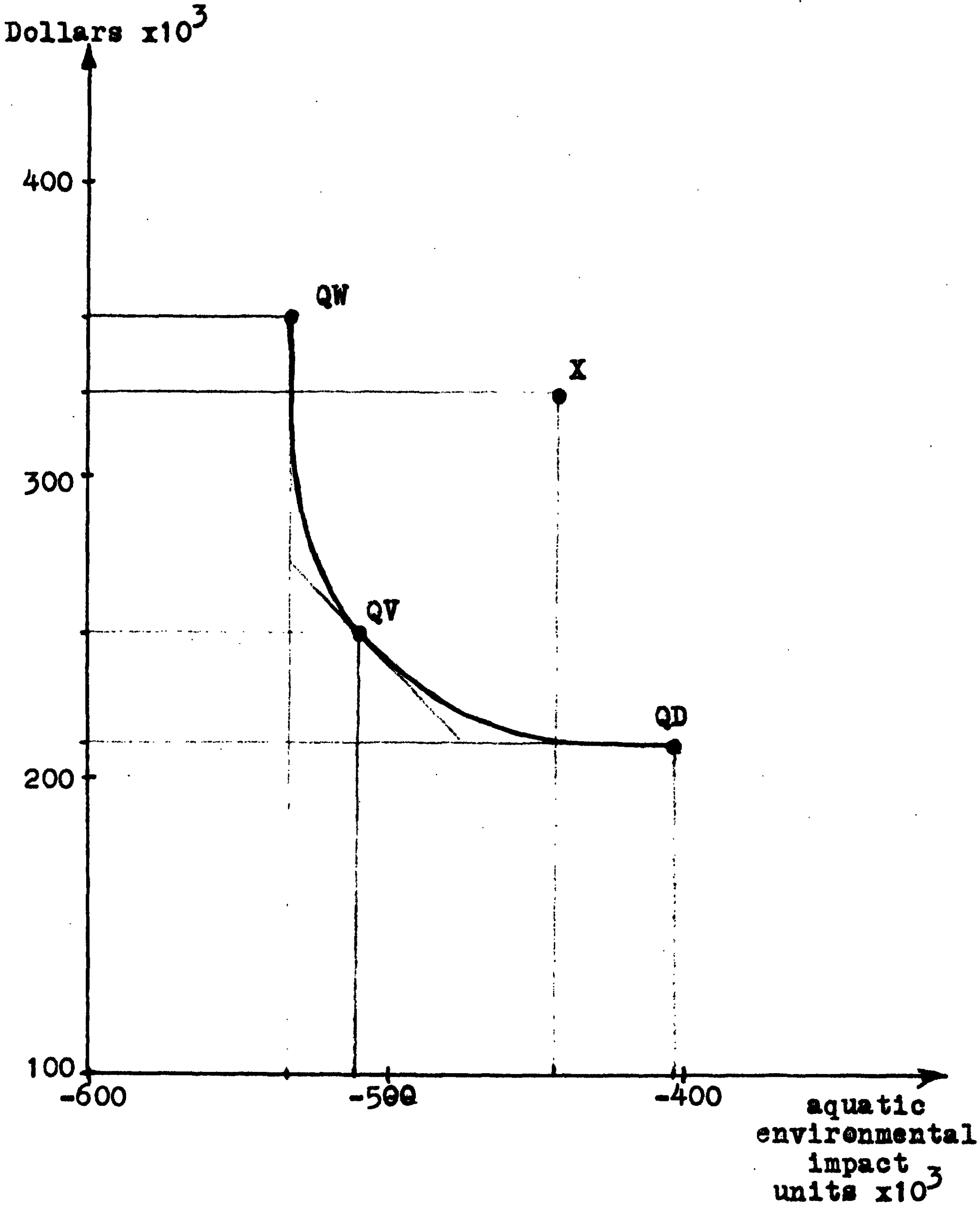

Figure 3.2.2-1 The tradeoff curve representing all possible optimum consequences of dollar and water pollution maintenance strategies at a standard reliability level.

Figures 3.2.2-2 and 3 are the dollar-environmental and dollar-air pollution curves as were those described in section 2.4.2 for the similar cases which concerned the unit commitment problem. Again here X marks the position of the first feasible solution computed for this problem.[13]

Also in the case of these maintenance tradeoff curves it is possible to display these three transform curves on one three dimensional plot, and this is shown in figure 3.2.2-4.

---

13. Even this is an optimistic estimate of where the fill-in-the-blank technique would probably leave the schedule, because this point represents the first feasible continuous variable schedule, which means that there would be an additional cost for changing the noninteger decisions to valid integer values. That is, this represents the first feasible solution for the linear case, which is probably an optimistic estimate of the value for the integer case.

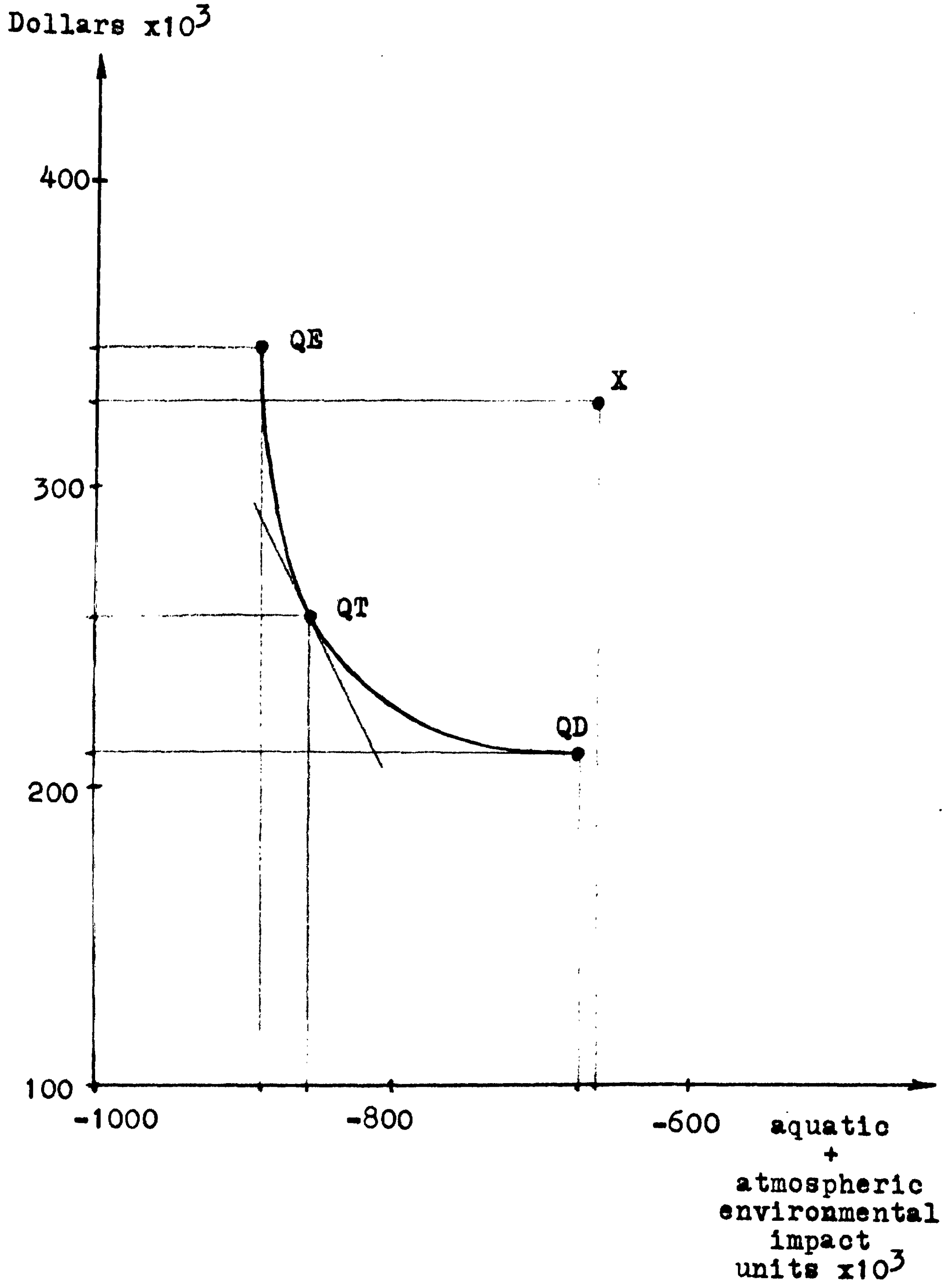

Figure 3.2.2-2 The tradeoff curve representing all possible optimum consequences of dollar and water+air pollution maintenance strategies at a standard reliability level.

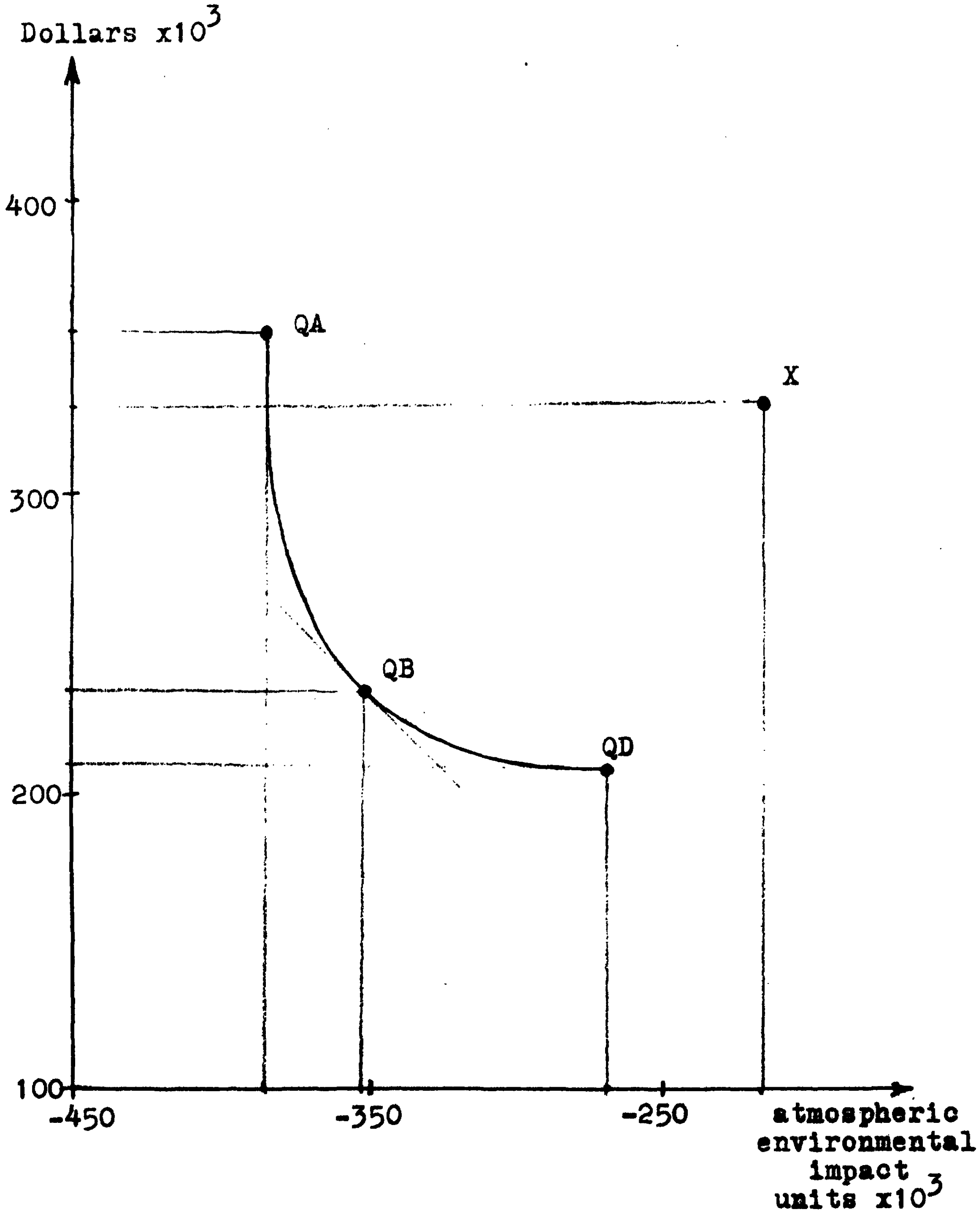

Figure 3.2.2-3 The tradeoff curve representing all possible optimum consequences of dollar and air pollution maintenance strategies at a standard reliability level.

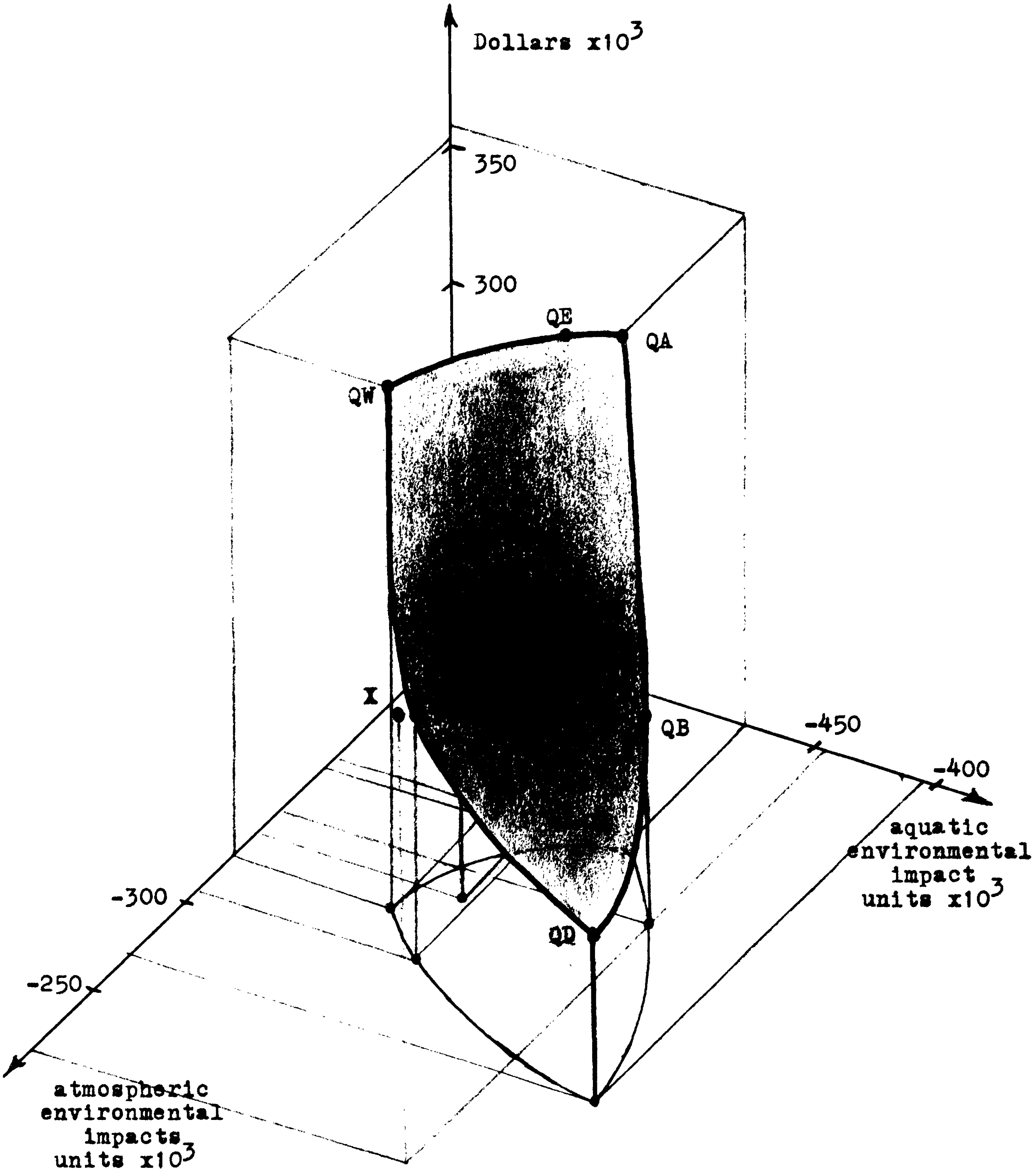

Figure 3.2.2-4 The transform surface associated with all optimum economic-environmental consequences of the maintenance and production schedule (standard reliability)

4. Transform Surfaces for Expansion Simulations

To meet expanding demands for power a great deal of planning is needed to determine exactly what new generation units will perform best when added to the power system. Either by intuition or by a manual or computerized screening program[14] attractive expansion schemes can be found, but these large, generalized programs cannot be expected to yield any great amount of detail or accuracy. For this reason there are a number of simulators in use by utilities which predict more exactly the dollar costs associated with specifically hypothesized, attractive expansion possibilities. The use of those same scheduling mechanisms described in chapter 3 for producing this type of simulation, will be demonstrated in this section.

Historically simulators have been used which were basically just probabilistic methods of meeting annual loading curves projected for the year being studied.[15] Using the assumption that the dollar costs of operating a unit are close to constant throughout the year, the loading triangle simulations remove time as a variable and work only with an ordered list of cheapest to most expensive power producing units and fill in a graph of capacity levels and the expected fraction of the year the load will exceed these levels.

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[14] Such a computerized program, which also includes some environmental considerations important to power plant siting, can be found in reference (11).

[15] See for an example reference (12).

However, introducing environmental impact measures generally[16] will cause the operating consequences to be quite definitely time variable.over the course of the year.

One obvious possibility for including time varying environmental impacts involves the development of a probabilistic simulator by extending current methods to include time and environmental impacts as additional dimensions. Although the results of such a simulator would not show accurately the precise splicing together of various generation components, this type of mechanism would probably yield a quick overview of the system performance, and thus, could be a promising area for future research.

Creating actual schedules of operation for the hypothetical systems is another way of performing simulations which include environmental impacts and time varying consequences, and it is this more precise method which will be demonstrated in this chapter.

Of the two types of schedulers developed, the maintenance and productions scheduler can obviously and straightforwardly be used as a simulator. The shorter time ranged scheduler has less obvious possibilities, and thus, the sample system simulator used here will explore the potential of this unit commitment scheduler as a simulation tool.

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16. It is possible to use measures which are not time varying and the probabilistic methods would here still be valid. For example, the aquatic impact measure could be the water temperature standard which must be met, ½° through say 6° C increases allowable, and the air pollution measure could be the percent sulfur content of the fuels allowable (4% to ½%).

4.1 Description of Sample Expansions

It is assumed that the maintenance and production scheduler has already simulated the long range performance of the hypothetical systems. The unit commitment simulation over the course of one week is now used as an aid to the comparison of the different systems' performances.

For this particular example to make this single week simulation a meaningful comparison mechanism it is assumed that the plants which are on maintenance in this particular week are common to the hypothetical systems to be studied. The remaining operating facilities which exist as a common base to which the different hypothetical expansions make additions include: plant 1, a relatively expensive (to operate) fossil fueled plant of 160 megawatts, with a moderately heavy air pollution factor (which varies, of course, as meteorological conditions change) and a cooling tower, thus, with very little thermal water pollution. Plant 2 is a 70 megawatt plant fueled with low sulfur content fossil fuel, making it slightly more expensive to operate but reducing its impact on the atmosphere. Plant 4 is an 80 megawatt gas turbine. And plant 7 is a 100 megawatt hydro-electric station.

The two expansion alternatives hypothesized involve the addition of four new fossil units, or the addition of two nuclear and two pumped hydro storage facilities.

The fossil addition alternative involves the hypothetical use of: plant 3, a typical 120 megawatt fossil fueled unit, plant 5 a 240 megawatt slightly cheaper fossil-fueled facility, and plants 3A and 3B which are both 460 megawatt relatively cheaply operated fossil fueled plants. All of these fossil plants on the average show more air pollution impact but slightly less water pollution impact than the nuclear facilities.

The nuclear-pumped hydro combinations involve: plants 6 and 6A, 560 megawatt nuclear plants with cheaper power, relatively more water pollution and little air impact when compared to the fossil plants, and plants 8 and 8A, pumped hydro storage facilities capable of storing 80 megawatts of power per hour, with a total storage capacity of 1000 megawatt hours, 80% input efficiency, and 83% output efficiency.

The nuclear, hydro and pumped hydro facilities have quotas for production and reservoir levels at the end of the week, with penalties associated with missing these targets. Unlike the scheduling problem, where quota costs are fixed expenses, the dollar costs associated with these quotas is vitally important in yielding comparable total costs of various alternatives. The hydroelectric quota cost is $5.2 per megawatt hour or $64,000, the pumped hydro cost is $5.35 per megawatt hour or $1,712, and the nuclear quota cost is $4.75 per megawatt hour or $760,000 for the weekly total quota.

The use of more than 400 megawatts of the large nuclear facilities cues the need for added system spinning reserve requirements.

Emergency standby power support is available for purchase from an external source at a few prespecified times. Bulk power purchases may be ordered for a couple of time slots in the week, but otherwise, all bulk interregional power transfers are assumed to have been previously settled (in the maintenance and production simulation) and the load demand curves have been adjusted in order to represent these transfers.

All of the simulations performed for this study used the scheduling mechanisms in the linear mode of operation for the purpose of increased computation speed. Although this linear mode introduces about a 1% error, this error is in the direction of decreasing the costs involved and is relatively predictable. Especially for the comparison of different systems where the errors in the different cases can be expected to be almost identical, it is felt that errors of this magnitude will not be relevant. to the

Measuring the capacity of the pumped storage facilities as 80 megawatts, which is the per hour energy input capability of the plant into the storage reservoir and the plant's per hour energy depletion when on full output, the total capacities of the fossil plan and the nuclear plan are equal, 1690 megawatts including portions of the old system which are held in common. Assuming 550 megawatts of the old system as scheduled down for maintenance, and assuming a 7% growth rate in the demand for power, then the magnitude of this expansion is what would be required at approximately 12 years in the future.

To demonstrate more vividly the usefulness of a unit commitment simulator two different load curves are used for that week which is 12 years in the future. The first demand curve, called the swing curve, is based upon an equal projected growth from all sectors of electric power users. Thus, the swing curve is basically a 'scaled up' version of the existing demand curves, and this is represented

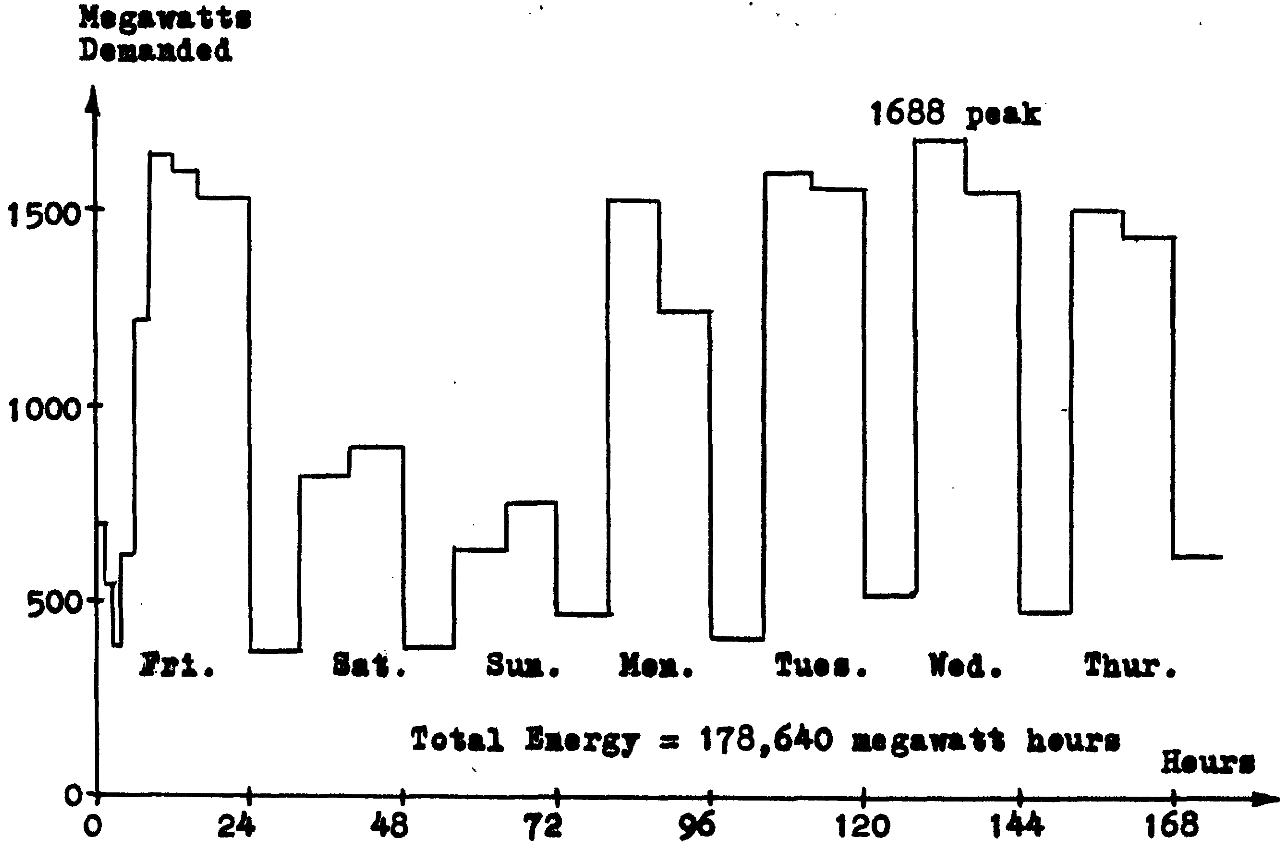

Figure 4.1-1 The load demand curve which represents the equal growths of all electric user sectors, called the swing curve.

in figure 4.1-1. The second curve, called the averaged curve, involves (1) the change in the industrial use pattern reflecting the use of more '3 days on- 3 days off' work weeks, perhaps motivated in part by cheaper weekend power rates, or taxes or disincentives for use of peak power[17], (2) the introduction of more electric heating[18] which would

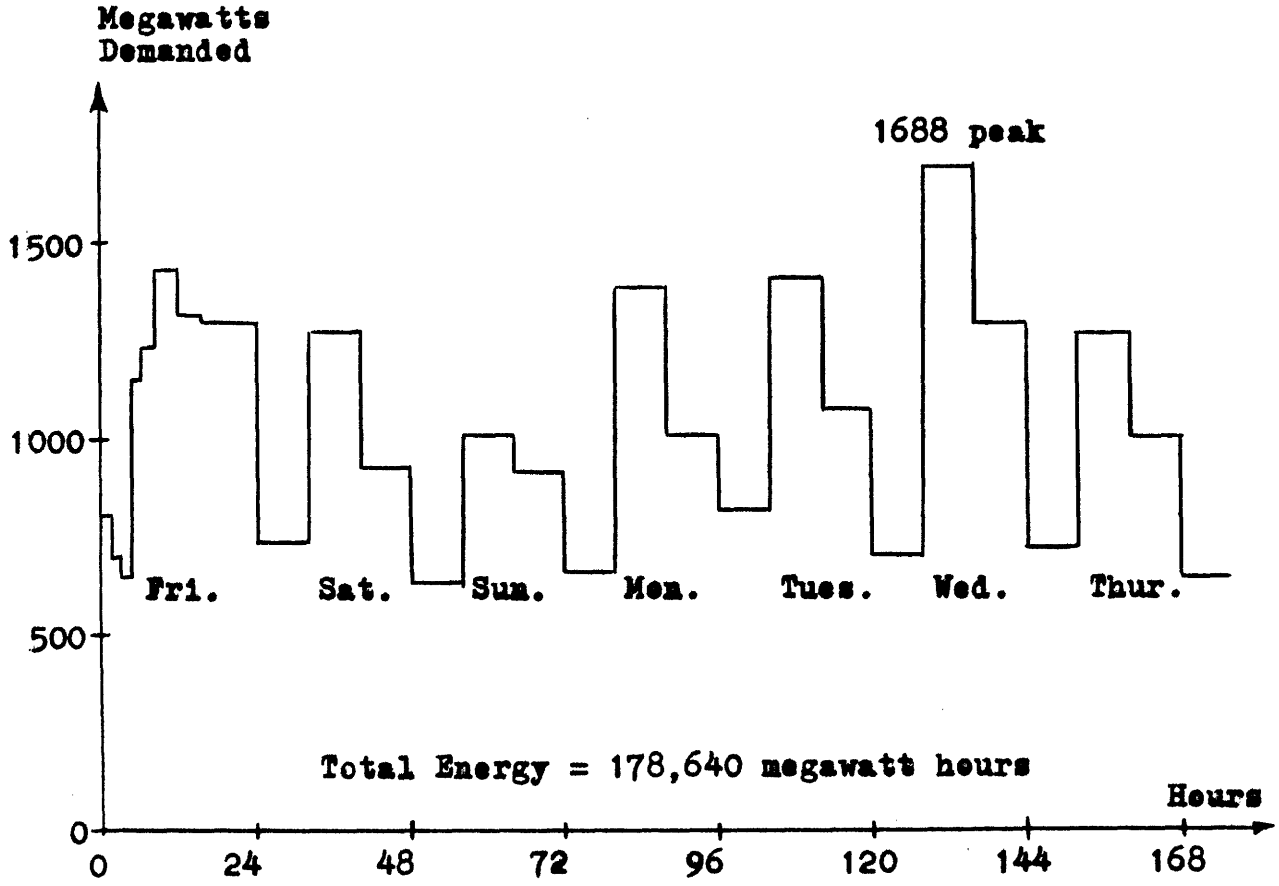

Figure 4.1-2 The load demand curve which represents the unequal growth rates which might exist for different sectors of electric users, called the averaged curve.

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17. See reference (13) for a lengthy description of possible electric rate and usage policy changes and how these might be reflected in growth patterns.

18. Much of the data for these demand curves was taken from, or motivated by, the information in reference (14).

slightly fill in the valleys of the demand curve, and (3) the use of electric cars, which would be charged at night and would greatly fill the demand valleys.

Both the swing curve and the averaged curve have identical peaks, 1688 megawatts, and identical total energy requirements, 178,640 megawatt hours, and thus, for simulators using only total energy and peak measures these curves would appear identical. The exact systems data and the exact demand curves used in this system, along with the spinning reserve requirements, can be found in Appendix F.

4.2 Comparison of Expansion Possibilities

The definitions of QD, QW and QA as the minimum dollar, water and air pollution schedules, and the definitions of QV, QB, QE, and QT as the dollar plus water, dollar and air, air and water, and dollar plus air plus water strategies are unchanged from section 2.4.1.

Of immediate interest are the minimum dollar costs possible from the two expansion alternatives as they are forced to meet the swing demand curve and the averaged demand curve. These results are shown on the next page in figure 4.2-1, and show that a sizable, about 11%, error can be made from the choice of an expansion scheme with reference only to the demand in terms of total energy and peak power requirements.

An examination of these results suggests that some

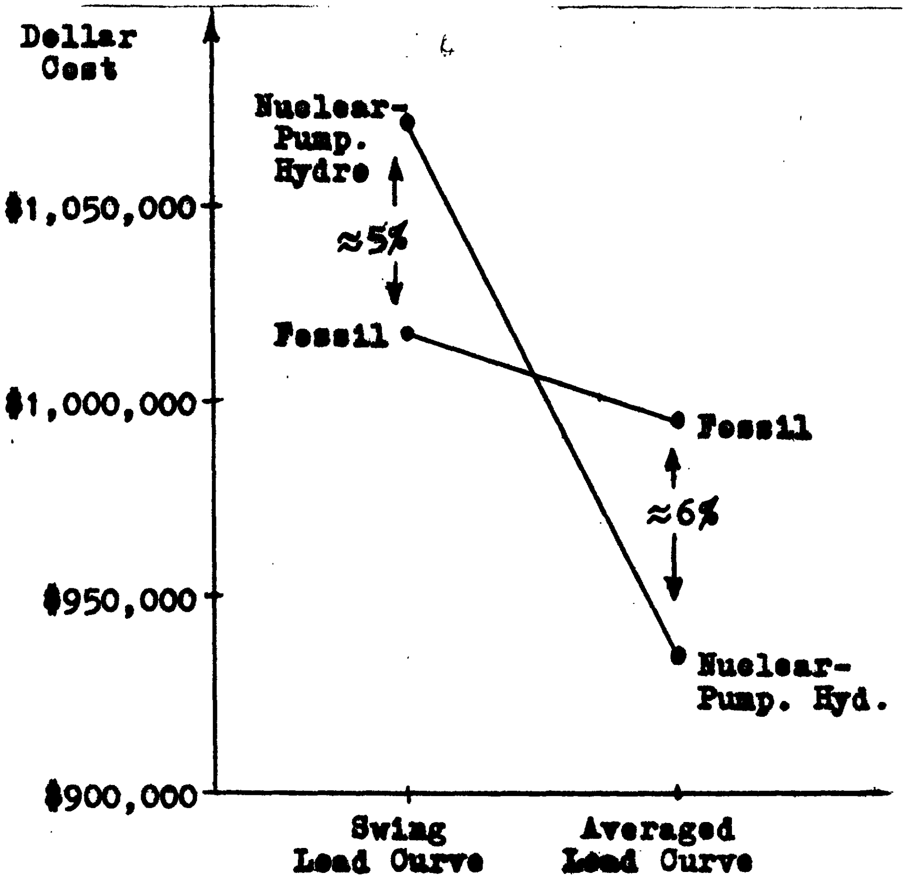

Figure 4.2-1 Dollar cost comparisons of meeting two different future load curve possibilities with hypothetical systems using four new fossil fueled additions, or using two new nuclear plants combined with two pumped storage plants.

sort of mix between the all fossil alternative and the all nuclear-pumped hydro might yield the best economic performance, or at least be less vulnerable to changes in future load shapes. A mixed system was created, including nuclear plant 6, pumped hydro plant 8, fossil plant 5 and fossil plant 3A, all added to the same original base system.[19] A same standard reliability measure was used for all the studies, and the results are given in figures 4.2-2 and 4.2-3. The exact

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[19] The overall capacity of this system was 60 megawatts higher than the capacities of the original systems.

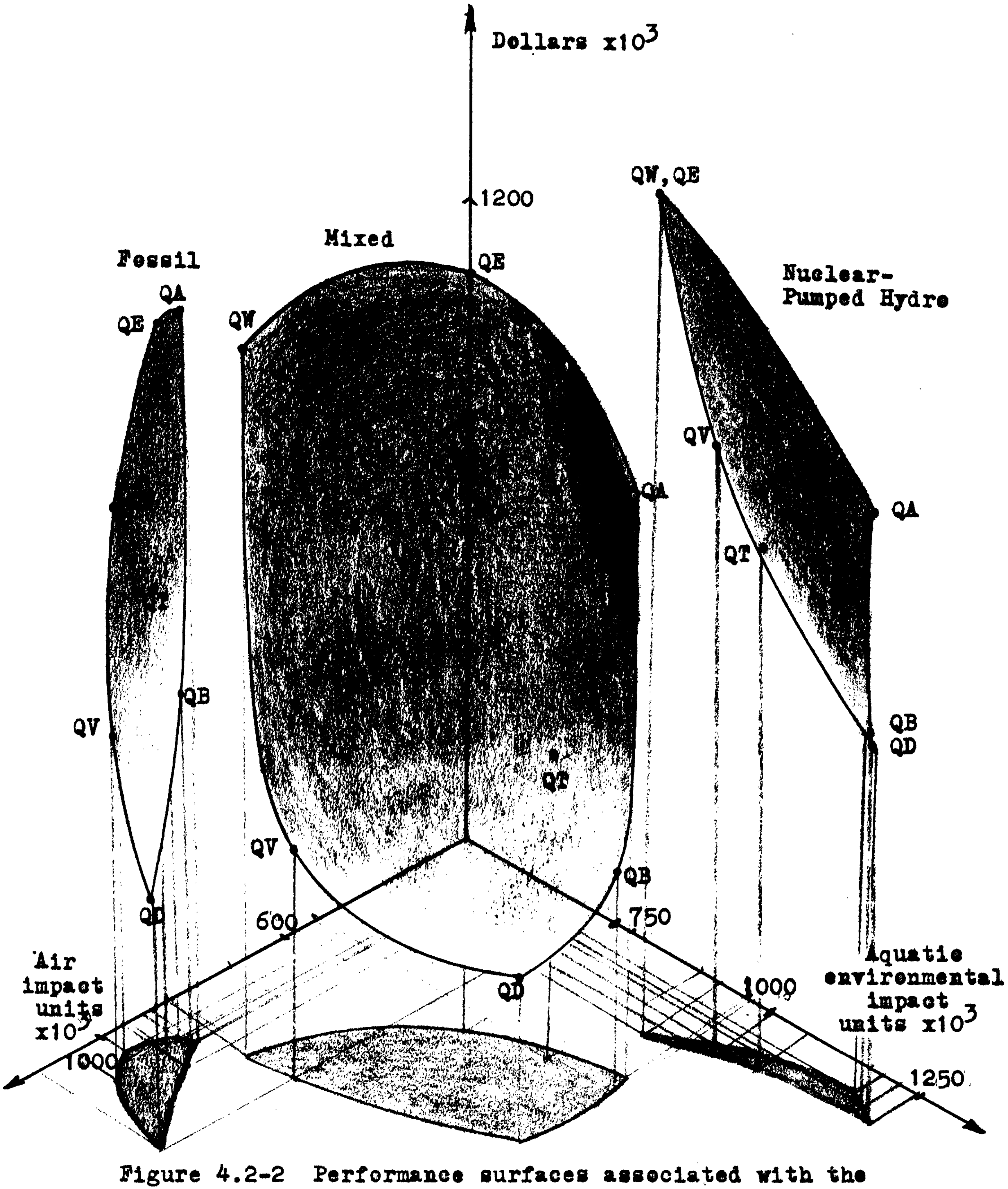

Figure 4.2-2 Performance surfaces associated with the swing load curve and the three expansion alternatives.

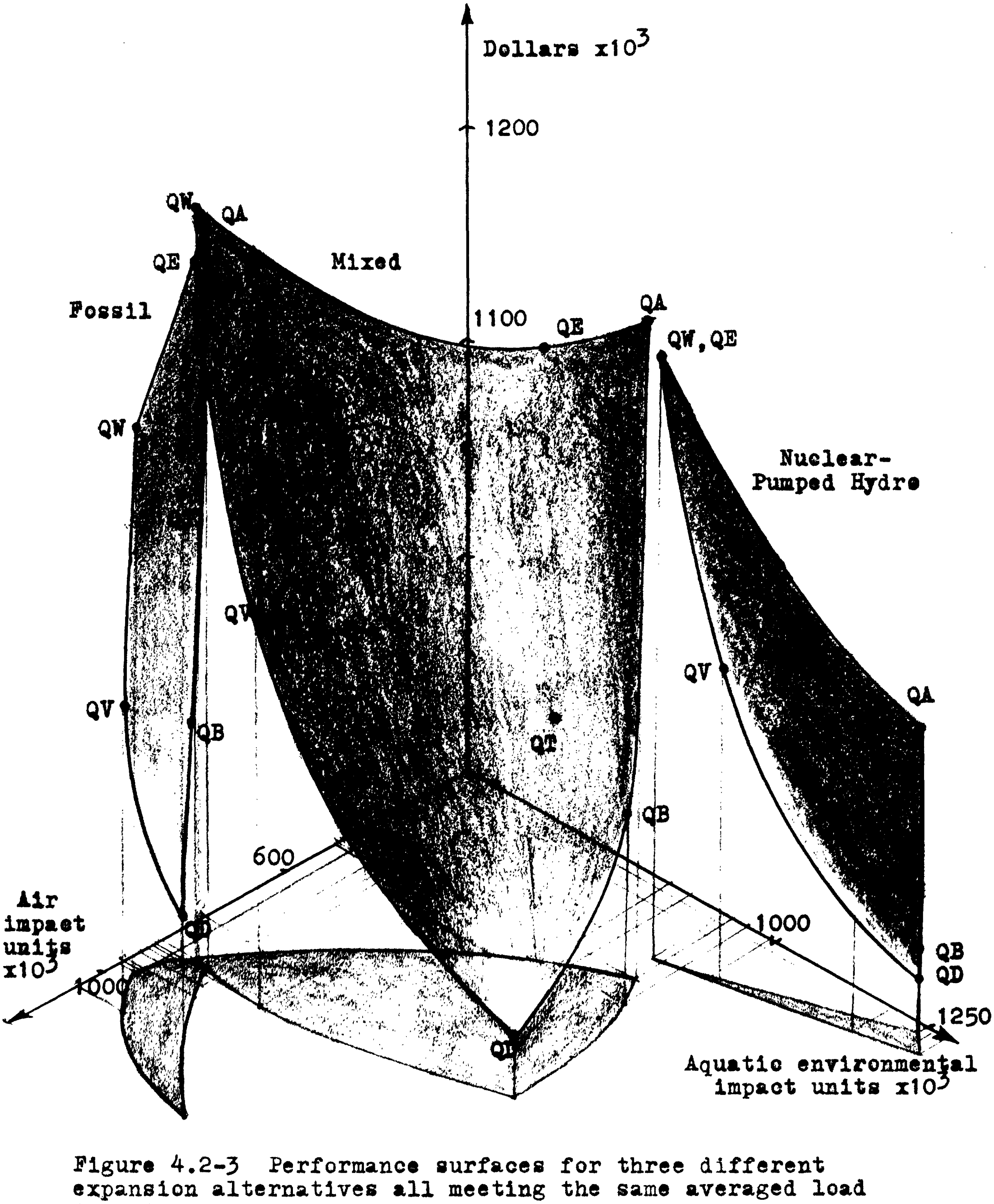

Figure 4.2-3 Performance surfaces for three different expansion alternatives all meeting the same averaged load demand curve

numerical results can be found in Appendix G.

Just a quick look at these performance surfaces shows that a mixed system affords a tremendous amount of additional flexibility, e.g. having available alternative configurations during intervals of relatively greater consequences from one aspect of system operation.

It would be naivity itself to flatly pronounce that in this particular case a mix would be the 'best' expansion strategy. A thorough understanding of the measures of environmental impacts is necessary before such a decision can be made, and then it is still a question of which interest groups definition of 'best' is used. An example of a case where the mixed system would be less desirable would be one in which the thermal impact to the aquatic community may be assessed as relatively harmless compared to the air pollution impacted upon the <u>human</u> environment, in which case the all nuclear-pumped hyrde system would be better. One of the most difficult tasks facing the planner is the prediction of future environmental standards and the effect these changes will have on the types of system components which should be ordered. Using the likely assumption that the regulations of the future will more accurately reflect the actual impact to the environment, the type of simulation tool presented here would be an ideal planning tool, with sensitive areas being avoided and potentially high impacting configurations sidestepped.

Further complicating the expansion decision making problem is the timing of plant additions. Other questions which must be considered when determining the desirability of any future system configuration include:

(1) what is the best system in the interim?
(2) will this plan lead to an attractive system 20 or 50 years from now?
(3) with the tremendous differences in the consequences of operation, what is the best order and timing for the introduction of the various facilities?
(4) how much flexibility is necessary with respect to the various load shape possibilities which might be[20] imposed upon the system in the future? and
(5) how will legislation concerning environmental standards change the shapes of these performance surfaces, and thus change the decisions concerning attractive expansion alternatives?

Thus, it can be seen that the entire expansion planning problem is not a static problem, but a problem which evolves through time and requires accurate load shape forecasts along the way and adequate attention to the sensitivity of system performance to changing environmental standards, construction and fuel costs, and fuel availabilities.

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20. Reference (15) represents some of the work being done in the field of modelling the demand curve from models of the growth of the different sectors of power users.

5. Feasibility and Usefulness

The issue presented here is not whether or not the scheduling techniques are valid, this has been discussed in references (5) and (6), but whether or not these transform surfaces can be produced and whether or not they will be useful.

Apparently, the question of usefulness is answered by their existence. They represent the answers to the types of economic and reliability questions asked of schedulers, as well as the answers to environmental questions which could not previously be answered.

The feasibility of producing these surfaces breaks down to the questions of (1) cost of producing them, and (2) the ability to make meaningful quantifications of environmental impacts.

Quantification of environmental impacts, if it proves to be too difficult as described in references (7) and (8), can be degenerated to something such as "BTUs into the water" and "tons of pollutants into the air." Even though this would not reflect as accurately the true environmental consequences, it appears that the resultant transform surfaces would still deserve careful investigation because the degenerate measures are not altogether meaningless.

The question of cost of producing these surfaces is treated in references (5) and (6). Although the speed with which these schedules, and thus the surfaces of which they are a part, can be computed makes the computation cost an unlikely barrier, even if this is a problem, a linear program degeneration of these schedulers would be useful. In most cases the error resultant from this method degeneration has resulted in errors of only about 1%. This would therefore be a valuable alternate method, and might be considered the primary method for rougher simulation work.

Appendix A

The following is the program which was used to solve the unit commitment problem shown in chapter 2.

```
/*MAIN  TIME=20,LINES=8
//JOBLIB  DD  DSNAME=SYS2.MPSX.LOAD,DISP=(SHR,PASS)
//OPTUCS01  EXEC MPSX
//MPSCOMP.SYSIN  DD  *,DCB=(RECFM=FB,LRECL=80,BLKSIZE=2000)
         PROGRAM
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                     *
*   THIS PROGRAM IS DESIGNED TO                                       *
*        1- REPRESENT THE THIRD EVOLVING STEP OF THE OPTIMUM UNIT     *
*          COMMITMENT SCHEDULER - OPTUCS  WHICH IS TO EXPLORE THE     *
*          VARIOUS SCHEDULING POSSIBILITIES FOR A HYPOTHETICAL        *
*          ELECTRIC POWER SYSTEM                                      *
*        2- OBTAIN UP TO 3 COMPLETE SCHEDULES WHICH WILL BE AT OR     *
*          VERY CLOSE TO THE OPTIMUM QUALITY FOR THE PRIORITIES AND   *
*          TRADEOFFS CHOSEN FOR THAT PARTICULAR STRATEGY              *
*        3- EXPLORE MANY DIFFERENT QUALITY MEASURES FROM MINIMUM      *
*          DOLLAR COST STRATEGIES TO MINIMUM ENVIRONMENTAL IMPACT     *
*          STRATEGIES WHERE ENVIRONMENTAL IMPACTS ARE FURTHER         *
*          VARIED COMBINATIONS OF AQUATIC AND ATMOSPHERIC IMPACTS     *
*        4- THEN STUDY THE MOVEMENT OF THIS TRANSFORM SURFACE AS      *
*          SYSTEM RELIABILITY REQUIREMENTS ARE EASED OR TIGHTENED     *
*                                                                     *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
         INITIALZ
         MOVE(XDATA,'MODEL')
         MOVE(XPBNAME,'PB1')
         CONVERT
         SETUP('BOUND','BD')
         MOVE(XOBJ,'QW')
         MOVE(XRHS,'MA')
         OPTIMIZE
         SOLUTION
         SAVE('NAME','OPTC')
         INIMIX
         MIXSTART('MATRIX')
         XMXDROP=2000000.
         CT=0
         MVADR(XDOPRINT,INT)
         MIXFLOW
STOP     MIXSAVE('NAME','TREE1')
         MIXSTATS('NODES')
         EXIT
INT      SOLUTION
         XMXDROP=2000000.
         CT =CT+1
```

```
          IF(CT.EQ.3,STOP)
          CONTINUE
*
CT        DC(0)
          PEND
/*
//MPSEXEC.MATRIX2  DD  UNIT=SYSDA,SPACE=(CYL,(5))
//MPSEXEC.MIXWORK  DD  UNIT=SYSDA,SPACE=(CYL,(5))
//MPSEXEC.SYSIN  DD  *,DCB=(RECFM=FB.LRECL=80,BLKSIZE=2000)
```

A brief summary of the data used to describe the system in the above program is contained below.

Minimum turn-on requirements and costs

Plant	Megawatt Minimum output	Average dollar cost, $	Average aquasphere cost	Average atmosphere cost	Turn-on cost, $
1	70	550	45	450	330
2	30	200	100	100	112
3	30	150	150	230	185
4	20	300	50	45	150
5	120	600	250	1250	402

First segment of loading curves

Plant	Megawatt output of segment	Average dollar cost, $	Average aquasphere cost	Average atmosphere cost
1	90	450	65	500
2	40	225	125	100
3	20	80	100	150
4	30	300	75	65
5	80	400	500	125

Second segment of loading curves

Plant	Megawatt output of segment	Average dollar cost, $	Average aquasphere cost	Average atmosphere cost
3	70	400	330	500
4	30	300	75	65
5	40	150	750	180

Nuclear and Hydro requirements and costs

Plant	Minimum megawatt output	Additional $ cost above quota $	Extent of mW additional loading	Startup cost
6	60	90	500	1019
7	5	15	95	184

Pumped Hydro Statistics

Plant	Pumping power used, max.	Input to storage per hour	Output from storage per hour,max.	Max. input to system	Startup cost $
8	96	80	80	64	119

Penalties for missing quotas

	Dollars	Water	Air
Overuse of nuclear energy	5.9	7.9	1.3
Underuse of nuclear energy	-4.1	-7.9	-1.3
Overuse of hydro energy	7.6	1.1	0.1
Underuse of hydro energy	-4.0	-1.1	-0.1
Overstorage in pumped hydro res.	-5.2	-1.1	-0.1
Understorage in pumped hydro res.	5.5	1.1	0.1

Nuclear energy usage target quota = 51,420 megawatt hours
Hydro energy usage target quota = 7,700 megawatt hours
Pumped hydro reservoir target level = 160 megawatt hours
Total storage capacity of reservoir = 1,000 megawatt hours
Initially all plants on except plant 8
Initially 100 megawatt hours in reservoir

There are six times during the course of the scheduling that emergency standby power support is available at $8 per megawatt and in quantities up to 3,000 megawatts. These times are at hours: 64,72,88,120,160 and 168.

There are 48 pages of additional data available for this particular example. This data is in the form of the exact computer listing of the program used. The additional information contained in this listing involves mainly the display of the time variations in environmental consequences. This listing, called pages A1 to A48, is available upon request.

Appendix B

The demand curves for standard and low reliability in the unit commitment problem are(high reliability is listed in reference (6)):

STANDARD

MA	D064	10480.		
MA	D072	8800.	D080	4400.
MA	D088	10080.	D096	8160.
MA	D104	5440.	D112	8000.
MA	D120	9600.	D128	3400.
MA	D136	7600.	D144	8000.
MA	D152	7120.	D160	10280.
MA	D168	8960.		

LOW

MA	D064	9020.	D072	7540.
MA	D080	3790.	D088	8820.
MA	D096	7230.	D104	4660.
MA	D112	6920.	D120	8620.
MA	D128	3100.	D136	6540.
MA	D144	7050.	D152	6320.
MA	D160	8950.	D168	7750.

The spinning reserve requirements are: **HIGH**

MA	SR064	12280.	SR072	10600.
MA	SR080	6200.	SR088	11880.
MA	SR096	9960.	SR104	7240.
MA	SR112	9800.	SR120	11400.
MA	SR128	5200.	SR136	9400.
MA	SR144	9800.	SR152	8920.
MA	SR160	12080.	SR168	10760.

and STANDARD

MA	SR064	11120.	SR072	9560.
MA	SR080	5550.	SR088	10880.
MA	SR096	9260.	SR104	6530.
MA	SR112	8800.	SR120	10520.
MA	SR128	4880.	SR136	8500.
MA	SR144	8920.	SR152	8030.
MA	SR160	10930.	SR168	9600.

and LOW reliability.

MA	SR064	10420.	SR072	8940.
MA	SR080	5190.	SR088	10220.
MA	SR096	8630.	SR104	6060.
MA	SR112	8320.	SR120	10020.
MA	SR128	4500.	SR136	7940.
MA	SR144	8450.	SR152	7720.
MA	SR160	10350.	SR168	9150.

Appendix C

The following is the program used in the solution of the maintenance and production scheduling problem of Chapter 3.

```
          PROGRAM
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                   *
*  THIS PROGRAM IS DESIGNED TO                                      *
*       1- SET UP THE MIXED INTEGER PROGRAM ASSOCIATED WITH THE     *
*          COMPLETE OPTIMUM PRODUCTION SCHEDULE - OPPROS.           *
*        2- SOLVE FOR THE OPTIMUM SCHEDULE IGNORING THE INTEGER     *
*          CONSTRAINT SETS                                          *
*        3- THEN OBTAIN UP TO  3 INTEGER SOLUTIONS , IF THEY EXIST, *
*          WITH DOLLAR PLUS ENVIRONMENTAL QUALITY MEASURES OF NOT   *
*          MORE THAN THE QUALITY OF A HAND COMPUTED SCHEDULE        *
*          USING SCHEDULING TECHNIQUES CURRENTLY IN COMMON USAGE    *
*        4- VARY THE DOLLAR COST AND ENVIRONMENTAL  WEIGHTINGS      *
*          FOR THE EXPLORATION OF ALL POSSIBLE OPTIMUM SCHEDULES    *
*          FOR A GIVEN LEVEL OF SYSTEM RELIABILITY                  *
*                                                                   *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
          INITIALZ
          MOVE(XDATA,'MODEL')
          MOVE(XPBNAME,'PB1')
          CONVERT
          SETUP('BOUND','BD')
          MOVE(XOBJ,'QW')
          MOVE(XRHS,'MA')
          OPTIMIZE
          SOLUTION
          SAVE('NAME','OPTC')
          INIMIX
          MIXSTART('MATRIX')
          XMADROP=2000000.
          CT=0
          MVADR(XDOPRINT,INT)
          MIXFLOW
STOP      MIXSAVE('NAME','TREE1')
          MIXSTATS('NODES')
          EXIT
INT       SOLUTION
          XMADROP=2000000.
          CT =CT+1
          IF(CT.EQ.3,STOP)
          CONTINUE
*
CT        DC(0)
          PEND
```

```
/*
//MPSEXEC.MATRIX2   DD   UNIT=SYSDA,SPACE=(CYL,(5))
//MPSEXEC.MIXWORK   DD   UNIT=SYSDA,SPACE=(CYL,(5))
//MPSEXEC.SYSIN   DD   *,DCB=(RECFM=FB,LRECL=80,BLKSIZE=2000)
```

The exact data used in this maintenance program is similar to that listed in the appendices of reference (5). For a precise listing, including the environmental impact data used, obtain Optional Appendix C, pages C1 to C11.

Appendix D

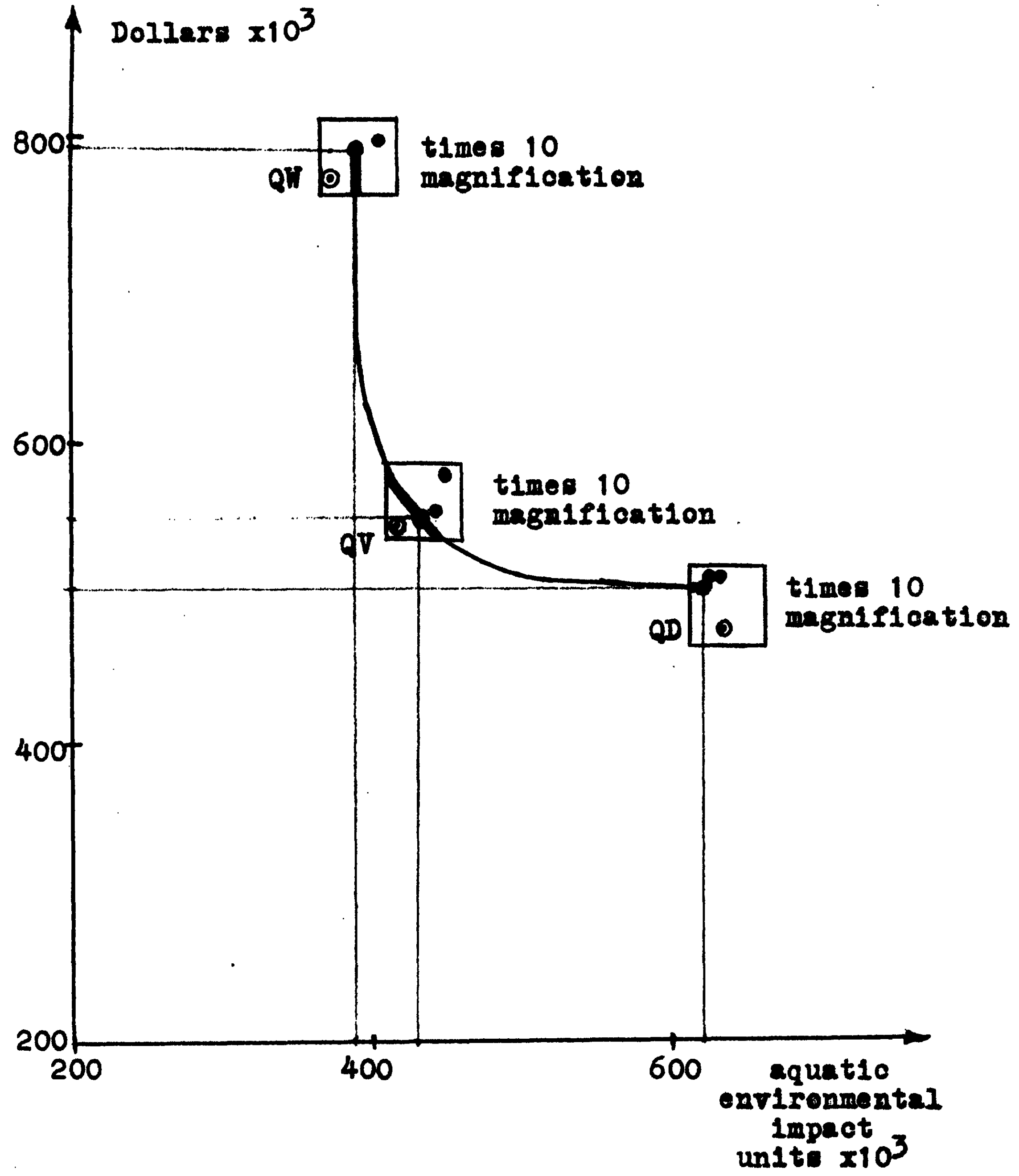
Contained here is the data which is a measure of the consequences of the various optimum schedules for the different unit commitment strategies, (from Chapter 2)

Standard Reliab.	Dollar Quality in dollars $x10^3$	Aquatic environmental impact units $x10^3$	Atmospheric environmental impact units $x10^3$
QW	795	390	411
QE	810	468	272
QA	784	585	227
QV	550	430	401
QT	542	493	287
QB	535	606	259
QD	503	622	332
Low Reliability			
QW	768	356	405
QE	786	451	242
QA	763	559	206
QV	514	399	392
QT	502	485	265
QB	484	574	260
QD	460	608	309
High Reliability			
QW	853	465	425
QE	861	516	328
QA	841	631	287
QV	644	497	419
QT	641	543	330
QB	635	652	305
QD	603	646	380

and for the different maintenance scheduling strategies:

QW	351.4	-534.8	-329.7
QT	254.7	-513.1	-341.6
QA	352.8	-480.8	-386.1
QE	346.3	-499.6	-385.9
QB	235.7	-444.1	-353.1
QD	210.6	-404.6	-269.0
QV	249.3	-511.7	-307.3
X	327.3	-444.4	-219.1

Appendix E



This is the tradeoff curve for the unit commitment 'dollar versus water pollution' strategies at standard reliability. The • show the consequences of the valid integer schedules produced, and the ⊙ show the position of the optimum linearly degenerated scheduling mechanism.

Appendix F

The following is the computer program used to solve the simulation of the hypothetical system expansion alternatives of Chapter 4.

```
/*MAIN  TIME=20,LINES=19
//JOBLIB  DD  DSNAME=SYS2.MPSX.LOAD,DISP=(SHR,PASS)
//OPTUCS01  EXEC MPSX
//MPSCCMP.SYSIN  DD  *,DCB=(RECFM=FB,LRECL=80,BLKSIZE=2000)
         PROGRAM
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                     *
*   THIS PROGRAM IS DESIGNED TO                                       *
*        1- REPRESENT THE SIMULATION OF THE OPERATION OF A UNIT       *
*          COMMITMENT SCHEDULER - OPTUCS  WHICH IS TO EXPLORE THE     *
*          VARIOUS SCHEDULING POSSIBILITIES FOR A HYPOTHETICAL        *
*          ELECTRIC POWER SYSTEM                                      *
*        2- OBTAIN SIMULATIONS OF SYSTEM OPERATIONWHICH REPRESENT     *
*          VERY CLOSE TO THE OPTIMUM QUALITY FOR THE PRIORITIES AND   *
*          TRADEOFFS CHOSEN FOR THAT PARTICULAR STRATEGY              *
*        3- EXPLORE MANY DIFFERENT QUALITY MEASURES FROM MINIMUM      *
*          DOLLAR COST STRATEGIES TO MINIMUM ENVIRONMENTAL IMPACT     *
*          STRATEGIES WHERE ENVIRONMENTAL IMPACTS ARE FURTHER         *
*          VARIED COMBINATIONS OF AQUATIC AND ATMOSPHERIC IMPACTS     *
*        4- THEN STUDY THE MOVEMENT OF THIS TRANSFORM SURFACE AS      *
*          POSSIBLE FUTURE SYSTEM COMPONENTS ARE ADDED                *
*                                                                     *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
         INITIALZ
         MOVE(XDATA,'MODEL')
         MOVE(XPBNAME,'NAME')
         CONVERT
         SETUP('BOUND','BD')
         MOVE(XRHS,'MA')
         MOVE(XOBJ,'QDO')
         OPTIMIZE
         SAVE('NAME','A')
         SOLUTION
         RESTORE('NAME','A')
         MOVE(XOBJ,'QDA')
         OPTIMIZE
         SAVE('NAME','B')
         SOLUTION
         RESTORE('NAME','B')
         MOVE(XOBJ,'QAO')
         OPTIMIZE
         SAVE('NAME','C')
         SOLUTION
```

```
          RESTORE('NAME','C')
          MOVE(XOBJ,'QAW')
          OPTIMIZE
          SOLUTION
          MOVE(XOBJ,'QWO')
          OPTIMIZE
          SAVE('NAME','E')
          SOLUTION
          RESTORE('NAME','E')
          MOVE(XOBJ,'QDW')
          OPTIMIZE
          SAVE('NAME','F')
          SOLUTION
          RESTORE('NAME','F')
          MOVE(XOBJ,'QDAW')
          OPTIMIZE
          SOLUTION
          EXIT
          PEND
/*
//MPSEXEC.SYSIN  DD  *,DCB=(RECFM=FB,LRECL=80,BLKSIZE=2000)
```

The demand for power at a certain hour, and the spinning reserve required at that hour are given in terms of the total megawatt hour requirement until the next time unit in the program. Thus, the first 3 segments represent the total demand over one hour, the next 2 over 2 hours, the next 2 segments represent the total requirement for the next 4 hours, and finally 8 hour intervals are used. The spinning reserve requirement includes the demand requirement, so for a pure spinning reserve number a subtraction must be made. Given first is the swing curve case, then the averaged curve,

```
    MA          D001        700.          D002         520.
    MA          D003        390.          D004        1250.
    MA          D006       2420.          D008        6560.
    MA          D012       6400.          D016       12400.
    MA          D024       3000.          D032        6700.
    MA          D040       7200.          D048        3100.
    MA          D056       5100.          D064        6100.
    MA          D072       3800.          D080       12200.
    MA          D088      10000.          D096        3300.
```

```
MA        D104      12800.          D112       12500.
MA        D120       4100.          D128       13500.
MA        D136      12400.          D144        3700.
MA        D152      12000.          D160       11500.
MA        D168       5000.
MA        SR001       860.          SR002        600.
MA        SR003       450.          SR004       1330.
MA        SR006      2620.          SR008       7250.
MA        SR012      7100.          SR016      13200.
MA        SR024      3300.          SR032       7350.
MA        SR040      8000.          SR048       3500.
MA        SR056      5600.
MA        SR064      6700.          SR072       4200.
MA        SR080     13400.          SR088      11000.
MA        SR096      3650.          SR104      13500.
MA        SR112     13200.          SR120       4500.
MA        SR128     14000.          SR136      13500.
MA        SR144      4100.          SR152      13000.
MA        SR160     12600.          SR168       5500.
```

and the averaged load demand and spinning reserve case is:

```
MA        D001        800.          D002         690.
MA        D003        650.          D004        2300.
MA        D006       2500.          D008        5700.
MA        D012       5200.          D016       10300.
MA        D024       5800.          D032       10100.
MA        D040       7300.          D048        5000.
MA        D056       8000.          D064        7200.
MA        D072       5200.          D080       11000.
MA        D088       8000.          D096        5600.
MA        D104      11200.          D112        8500.
MA        D120       5400.          D128       13500.
MA        D136      10200.          D144        5600.
MA        D152      10000.          D160        7900.
MA        D168       5000.
MA        SR003       800.          SR004       2530.
MA        SR001       960.          SR002        850.
MA        SR006      2750.          SR008       6250.
MA        SR012      5720.          SR016      11400.
MA        SR024      6300.          SR032      11200.
MA        SR040      8000.          SR048       5500.
MA        SR056      8800.          SR064       7920.
MA        SR072      5780.          SR080      12100.
MA        SR088      8800.          SR096       6160.
MA        SR104     12300.          SR112       9350.
MA        SR120      5980.          SR128      14000.
MA        SR136     11300.          SR144       6100.
MA        SR152     11000.          SR160       8610.
MA        SR168      5520.
```

A brief summary of the data used to describe the system in the above program is presented below. Where there were time varying quantities, such as in the environmental impact numbers, the approximate average of the figures is given.

Minimum turn-on requirements and costs

Plant	Minimum megawatt output	Average dollar cost, $	Average aquasphere cost	Average atmosphere cost	Startup cost, $
1	70	564	48	495	330
2	30	314	100	100	112
3	30	170	160	225	185
3A	60	400	270	400	590
3B	60	400	270	400	590
4	20	325	50	45	150
5	120	600	250	900	402

First segment of loading curves

Plant	Megawatt output of segment	Average dollar cost, $	Average aquasphere cost	Average atmosphere cost
1	90	455	80	450
2	40	221	125	100
3	20	80	100	150
3A	400	2300	1800	2600
3B	400	2300	1800	2600
4	30	303	65	75
5	80	390	500	125

Second segment of loading curves

Plant	Megawatt output of segment	Average dollar cost, $	Average aquasphere cost	Average atmosphere cost
3	70	390	325	500
4	30	315	65	75
5	40	161	320	1000

Nuclear and hydro requirements and costs

Plant	Minimum megawatt output	Additional $ cost above quota $	Extent of additional mW loading	Startup cost
6	360	32	200	8500
6A	360	32	200	8500
7	5	15	95	184

Pumped hydro statistics

Plant	Pumping power used, max.	Input to storage per hour	Output from storage per hour, max.	Maximum input to system	Startup cost
8	96	80	80	64	119
8A	96	80	80	64	119

Penalties for missing quotas

	Dollars	Water	Air
Overuse of 6 nuclear energy	5.9	7.9	1.3
Underuse of 6 nuclear energy	-4.1	-7.9	-1.3
Overuse of 6A nuclear energy	5.9	7.9	1.3
Underuse of 6A nuclear energy	-4.1	-7.9	-1.3
Overuse of 7 hydro energy	7.6	1.1	0.1
Underuse of 7 hydro energy	-4.0	-1.1	-0.1
Overstorage in 8 pumped hydro res.	-5.2	-1.1	-0.1
Understorage in 8 pumped hydro res.	5.5	-1.1	-0.1
Overstorage in 8A pumped hydro res.	-5.2	-1.1	-0.1
Understorage in 8A pumped hydro res.	5.5	1.1	0.1

Nuclear energy usage of 6 target quota = 80,000 megawatt hours
Nuclear energy usage of 6A target quota = 80,000 megawatt hours
Hydro energy usage at 7 target quota = 14,000 megawatt hours
Pumped hydro reservoir 8 target level = 160 megawatt hours
Pumped hydro reservoir 8A target level = 160 megawatt hours
Total storage capacity of reservoir 8 = 1,000 megawatt hours
Total storage capacity of reservoir 8A = 1,000 megawatt hours
Initially 205 megawatt hours stored in reservoir 8
Initially 205 megawatt hours stored in reservoir 8A
Initially all plants on except plants 8 and 8A

There are fifteen times during the course of the scheduling when emergency standby support is available for purchase from external sources at a price of $8 per megawatt and in quantities up to 3,000 megawatts per hour. These times are at hours: 8, 12, 16, 64, 72, 80, 88, 104, 112, 120, 128, 136, 152, 160 and 168.

Bulk power purchase options available

Hour	Megawatts available	Dollar cost per megawatt
24	25	$5.75
40	75	$5.17
128	400	$6.25

The amount of .00001 times the dollar cost of the various programs was added to the measure of desirability of the purely environmentally oriented strategies. This was done to insure that dollars were not spent without any cause. For example, power purchases had only dollar costs, and thus if dollars were not considered at all, it would be possible that the program would ask for power purchases that were not needed being irrelevant to the desirability measure used. These added dollar costs are not, however, reflected in the results presented (they have been withdrawn because they do not represent real environmental costs).

There are 88 pages of additional data available for this particular example. This data is in the form of the exact computer listing of the program used. The additional information contained in this listing involves primarily the display of the time variations in environmental consequences. This listing, called Optional Appendix F, and containing pages F1 through F88, is available upon request.

Appendix G

Contained here is the data which is displayed in Chapter 4. The points QD, QA, QW, QB, QV, QE and QT are strategies of desirability explained in section 4.2. The costs D, A and W represent the qualities of the particular optimum simulations in terms of dollar costs, atmospheric environmental impact units and aquatic environmental impact units, respectively.

Plan → Demand →		Fossil Swing	Mixed Swing	Nuclear Swing	Fossil Averaged	Mixed Averaged	Nuclear Averaged
QD	D	1018880	978944	1070522	994709	931541	935102
	A	1184550	717642	284822	1210161	771416	255502
	W	703880	964436	1245172	724663	992713	1286622
QA	D	1245360	1174320	1178442	1252720	1208171	1040622
	A	889340	481482	245262	890410	419364	213592
	W	580980	965736	1190742	573320	932740	1255702
QW	D	1155070	1231198	1294492	1154530	1264748	1181282
	A	980820	854108	356102	964850	909967	355052
	W	537020	651453	931602	526510	588345	925292
QB	D	1073030	1020155	1076402	1046480	987041	941812
	A	948210	514347	265042	958520	476151	235652
	W	601300	975331	1218192	596630	953125	265902
QV	D	1059610	1093222	1186642	1043490	1084958	1046722
	A	1047090	853952	340932	1060170	889621	337682
	W	573100	718805	1001282	569080	668146	1015132
QE	D	1233940	1255238	1294492	1224530	1189480	1181282
	A	893810	575879	356102	889260	481393	355052
	W	564450	774253	931602	557430	831724	925292
QT	D	1117320	1041790	1141322	1122810	1019416	1000692
	A	920340	532559	303112	904200	484359	291752
	W	568040	887348	1066712	557170	865819	1197432

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