A METHODOLOGY FOR ASSESSING ECONOMIC RISK OF WATER SUPPLY SHORTAGES

FINAL REPORT

A METHODOLOGY FOR ASSESSING ECONOMIC RISK OF WATER SUPPLY SHORTAGES

IWR

INSTITUTE FOR WATER RESOURCES

DEPARTMENT OF THE ARMY
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IWR Report 72-6

INSTITUTE FOR WATER RESOURCES

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final report

A METHODOLOGY FOR ASSESSING ECONOMIC RISK OF WATER SUPPLY SHORTAGES

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prepared by

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Water Resources Engineers, Inc.
Springfield, Virginia

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FOREWORD

A. Purpose

This research is devoted to developing a proceedure for estimating the frequency-damage relationship resulting from a water shortage in an urban area. The area under the frequency-damage curve could be construed as average annual damages from the range of possible water shortages and is similar to the calculation of average annual flood damages by the Corps of Engineers and others.

B. Findings

The researchers have developed a proceedure for estimating income losses associated with varying degrees of water shortage which combined with the frequency of shortage results in the frequency-damage relationship. An empirical test of the proceedure was developed for the York, Pennsylvania Water Service Area.

C. Assessment

The report presents both a proceedure and a test of the proceedure for an area which experienced a substantial water shortage in 1966. The results portray a vivid picture of the reaction of various interest groups in the York community to the drought. The water company proposed a set of rules which would reduce consumption rates to conserve the limited available supply. As is the typical case of management under uncertainty, exhaustion of available supply was avoided by the restriction on consumption and the eventual recurrence of normal percipitation which refilled the storage resevoirs. The water company management pursue their investment plans in a way that minimizes risk of substantial shortage by bringing in additional storage to buffer the difference between projected long term consumption patterns and the rainfall runoff pattern implied by historical records. Of course, historical records may not reveal the most serious potential deficiencies in runoff. In the case study, there was considerable pressure exerted to force the water company to place a fairly expensive temporary pipeline in operation to divert flows from the Susquehanna River to York. The company preferred to stick to long range plans which would develop additional storage in the local basin. Eventually the rains came, pressure for the temporary pipeline was reduced and the additional resevoir was constructed.

The report estimates average annual income losses due to water shortage for the defined region. Before these income losses are construed to be benefits to the provision of additional water, several difficult definitions must be made. The definitions must be consistent with the boundaries relative to the decision maker considering the benefits and costs who will ultimately bear the investment decision. From the water company's perspective only changes in revenue from water sold should be relevant--however the pressure of water users who would suffer actual or potential losses would be real and substantial. From the perspective of the community bounded by the water service area, those income losses identified by the report might be relevant. However, from the national accounting stance preferred in the analysis of benefits and costs for federal programs choices, the boundaries would have to be relaxed and different values would be attached to the income losses.

This case study is valuable to students and planners working with urban water supply problems as it opens the way to an alternative method of assessing the benefits for adequate municipal water supplies; it distinguishes between short run and long run plans; and the role which each plays in resource development planning.

D. Status

This work represents the findings, conclusions and independant judgements of the team of researchers. Their conclusions are not construed to necessarily represent the view of the Corps of Engineers. Policy and proceedural changes which may result from this research will be implemented by direction and guidelines provided by the Chief of Engineers through command channels.

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FOREWORD

This project had its official genesis in the 1969 annual report of the Institute for Water Resources (IWR), in which the following statement is made:

> "Today, as in the past, periodic water shortages frequently occur, but there is little knowledge of how individuals in households and how industries of various types and sizes react to periodic water shortages. The research program now outlined seeks to determine the adjustments made to water shortage and to estimate the short and long-run consequences and cost incurred, directly and indirectly."

In April, 1970, discussions were held between IWR and Water Resources Engineers, Inc. (WRE) which suggested as appropriate research, an exploratory study aimed at a more penetrating perception of the shortage problem. Subsequent discussions were held and WRE initiated this project, "Economic Risk of Water Supply Shortages," which is directed toward development of a methodology and its testing in order to contribute a technical basis for planning research in the field of water supply by the IWR or other elements of the Corps of Engineers. The project commenced on January 15, 1971 and devoted about two man-years of effort to the study. Several possible study areas were considered to test the methodology and it was decided to concentrate on the York, Pennsylvania area.

A substantial amount of the data used in this study came from official U. S. Government sources; principally the Bureau of the Census, the Bureau of Domestic Commerce and the U. S. Geological Survey. Other information came from personal interviews with all of the large water-using industrial firms in the area served by The York Water Company and from questionnaires mailed to nearly 20,000 of the company's residential customers. Also interviewed were many public officials, including the mayor, several of the important commercial water users and both of the large local newspapers.

The initial steps in WRE's analytical procedure were to obtain data on:

1. The area's hydrology,
2. Supply and the demands placed upon it by its various classes of customers, and
3. Responses of such customers to the 1966 water shortage.

The interviews with each of the 23 large water-using industrial firms, which account for 85% of the industrial usage in York, provided answers to a carefully prepared list of questions; especially on how each firm would be likely to cut back production in response to specific levels of future water shortages. Such cut-backs were then translated into lost wages. Losses suffered by residential customers during the 1966 water shortage were solicited by questionnaire.

We wish to acknowledge the cooperation received from individuals contacted in the York area. Particular mention should be made of Mr. Roland Y. Smith, General Manager of The York Water Company and his predecessor, Mr. John G. Redman, who were generous of their time and resources in providing detailed data on the water company's operations during the shortage period in 1966. Assistance was also received from officials of the Manufacturers Association of York, Pennsylvania, the York County Planning Commission and the York County Industrial Authority. The local newspapers, the York Dispatch and the York Daily Record were very helpful in making their files available to us on their almost day-by-day reporting of developments during the 1966 water shortage.

The source of the original idea to pursue this study area was W. Green of the Economic Research Service of the Department of Agriculture. The government technical contact for IWR was R. W. Harrison. In this regard, he and L. G. Antle, also of IWR, furnished several good ideas. IWR also put WRE into contact with Pennsylvania State University staff. A meeting with Professors G. Aron and T. M. Rachford provided a means for information exchange.

Consultants on this program who made valuable contributions were D. H. Moreau of the Department of City and Regional Planning at the University of North Carolina, and E. D. Bovet, Consulting Economist, formerly Economic Advisor with the U. S. Office of Saline Water. Suggestions were also made by C. S. Russell of Resources for the Future and co-author of Drought and Water Supply, and H. Schwartz of the New York District Office of the Corps of Engineers.

The WRE study team on this project was comprised of G. K. Young, R. S. Taylor and J. J. Hanks, the former being responsible for overall direction of the project. The same individuals were largely responsible for the writing of this report. Valuable inputs on developing the methodology were made by G. F. Tierney. Technical assistance, especially in the development and implementation of the computer model, was provided by J. S. Selekof. Additional assistance, particularly in evaluating responses of residential customers to the questionnaires was provided by M. R. Childrey, J. L. Matticks, and C. W. Forlini. The latter also performed the considerable amount of drafting required for the many figures in this report.

The typing was performed by P. Felker and K. Browne.

1. INTRODUCTION

The objectives of this study are:

1. To define technically adequate means and procedures for estimating probability-loss functions for water supply shortages in urban areas of households and industrial commercial users. Concern will center upon probable short and, to the maximum extent practicable, long-run economic losses arising from specific water supply and use situations, and upon development of adequate definitions and measures of drought and of response to drought.

2. To determine and refine through sample studies the kinds of statistical information required to adequately estimate the probable aggregate effects of intermittent water shortages over integrated water supply areas covering typical urban conditions and water distribution systems.

In addition, there exists a need for a determination of responses to a water shortage by each of the important classes of customers (residential, commercial, and industrial) both from a short-run as well as a long-run standpoint. Consequently, this need has been considered during the course of the work.

The main problem solved in this project is the development of a methodology to determine regional[1] losses and risks associated with an urban-industrial area for actual and potential water shortage conditions. The sectors which suffer the losses are identified. Sector losses which cross the regional boundary are considered to be regional losses. Thus,

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[1] The term "regional" may have different meanings; for example, regional may imply an area the size of the Northeastern United States. In this report, smaller areas are assumed and are on the order of the size of a Standard Metropolitan Statistical Area.

a regional perspective is maintained; future work could shift perspective to individual sectors with only slight procedural changes. Although intraregional sector losses are not the focus, they are analyzed as a part of this study.

It is anticipated that this methodology will be used as a planning tool, not only for estimating requirements on future water supplies, but in allocating short supplies during emergency conditions. The planning tool should assist water resource planners and system managers throughout the country.

In order to develop this methodology, it is necessary to define a water supply shortage. By including all important facets of the problem, a general but encompassing definition of shortage resulted. Specifically, a water supply shortage is defined as *any time the water purveyor chooses, or is forced into, a position where he cannot supply the total demand for water in the system.* This definition includes many events which can lead to or cause a shortage. Some of these are the following:

1. Inadequacy of the present water supply,
2. Population and industrial growth,
3. Increases in water use reflected by a larger per capita demand,
4. Irregular periods of meteorological drought or seasonal deficiencies in supply,
5. Inability to meet peaks in the demand, including seasonal, monthly, weekly or even hourly, drafts,
6. Denials of additional hook-ups to the system that would cause an increase in demand,
7. Hedging during a period when water is on hand, but future forecasts indicate insufficient supply from principal source,

8. Operating policies of a water manager, and
9. Improper commodity pricing.

In many urban-industrial areas the demand for water by certain customers is based principally on their usage, almost regardless of price. In other areas where water rates are high, price becomes a much more important factor in determining demands.

There are, however, two main components that can lead to a water shortage - the possible inadequacy of the water system itself, or shortcomings in the operating policies of the water manager. Figure 1-1, "System Evaluation of Shortage," illustrates this concept. The interaction of these two components, with particular emphasis on the water manager who may be able to operate efficiently despite inadequacies of the water system, determines whether the system yields a supply that meets, or fails to meet, the demand.

When a shortage occurs, there are both short and long-term effects. As illustrated in Figure 1-1, a shortage generally results in:

1. Certain short-term economic losses to customers and to the water supplier as well, and
2. Long-term adjustments requiring various economic inputs that are necessary to improve the system to meet demands over the long term.

Even when no shortage problem exists for the short term, certain economic inputs must be made to maintain system adequacy for the long term.

An integral part of the system evaluation set forth in Figure 1-1 is the last component, re-evaluation. For example, it is possible that the major cause of the water shortage was faulty pricing, inept operating procedures or bad judgment in expanding supply facilities. In short, periodic re-evaluation of the utility's basic policies, especially during or after a water shortage, can minimize the risks of future shortages and their consequent economic losses.

The definition of water shortage permits development of a procedure to analyze the short and long-term responses of various water suppliers and consumers to actual water shortages. Such analysis is essential in evaluating both the tangible and intangible effects involved so that reliable loss functions can be developed for future water supply shortages. Major aspects of shortage analysis include:

1. The water utility's present supply-demand situation and the importance of management's decision making process during a shortage period - generally under considerable pressure from social and political elements in the community.
2. The short-term economic effects of such shortages, based largely on the responses of the suppliers and all consumers involved, translated into actual dollar figures including revenue losses, additional capital and operating costs, and various economic losses resulting from restricted water uses.
3. The long-term economic effects, based largely on the future planning response of water managers and their superiors (also influenced by social and political forces) translated into actual capital costs of making the required facility expansions, and the "present value" of such costs. Also to be considered are the additional operating costs for such facilities, possible increases or decreases in revenues (especially if water demands are restricted) and the long-term effects of such decisions (some of which could conceivably be beneficial) to customers. Finally, the investments of various industrial firms and other large water users for installing re-circulating equipment and possibly other facilities to supplement existing water supplies should be considered.

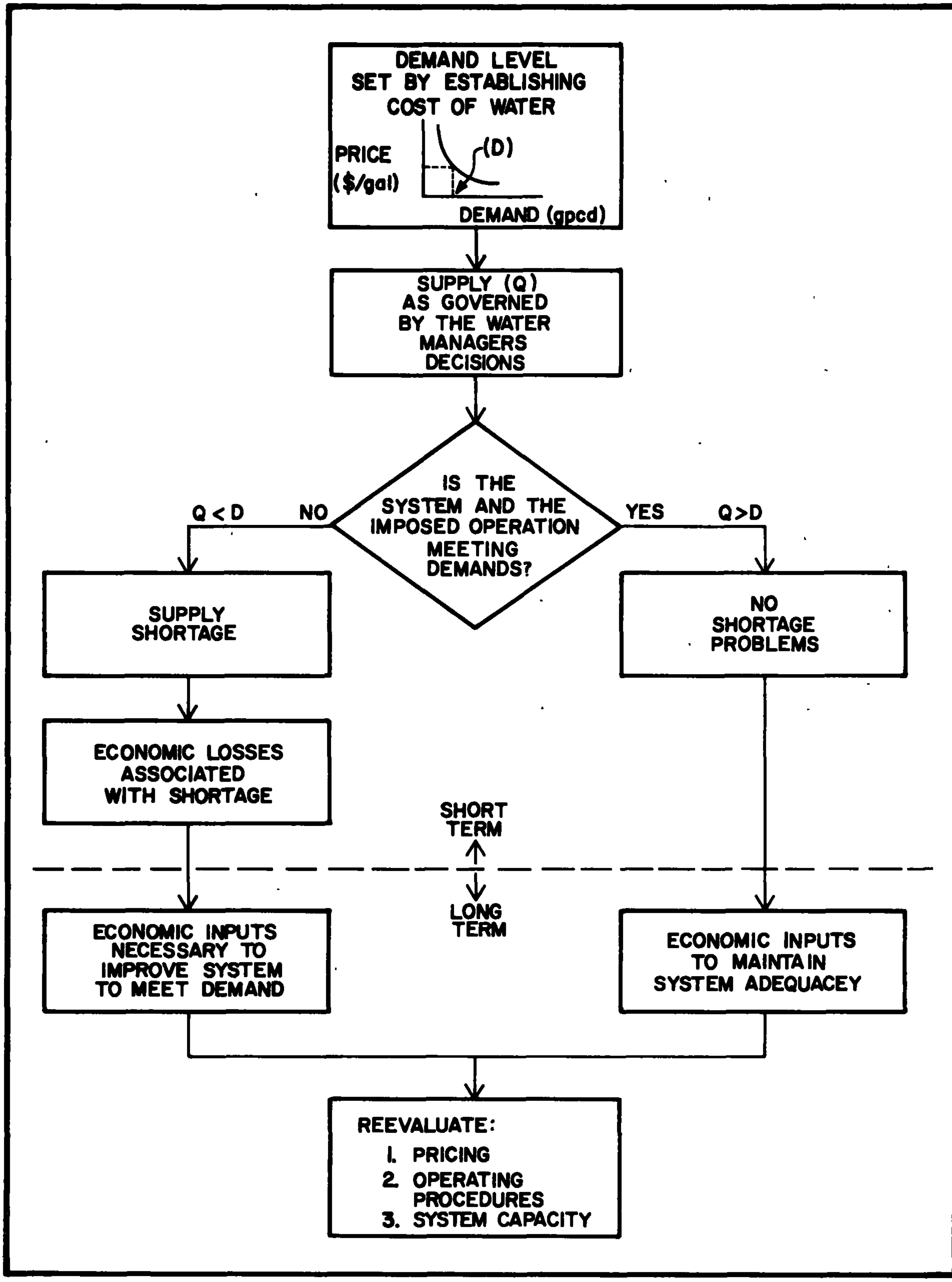


FIGURE 1-1
SYSTEM EVALUATION OF SHORTAGE

After all the physical and economic data necessary to define the system are collected and analyzed, a simulation of the economic response is made. The simulation makes it possible to reproduce the events of the shortages and correctly assess their economic impacts. Using simulation, one can study the interrelationships between the important variables and the economic responses of the system.

The simulation is computerized and estimates the economic losses resulting from an urban water shortage. The basic elements of the simulation are a stream which furnishes the main water supply to the urban area, a reservoir, a water company manager who manages the system and alternate water supply sources such as rivers and quarries. Data for the simulation consists of the projected population of the area for the time period being simulated, the water demand expected for this period, the hydrology of the supply stream, the reservoir storage and information describing how the system is to be managed.

The area being analyzed is divided economically into four sectors: municipal, industrial, commercial, and domestic. The economic losses incurred by each of these four sectors during a water shortage are calculated. The economic losses to the area during a water supply shortage are considered as those losses from each sector which are not gained or "made up" by another sector.

The specific application of the simulation within an optimization framework, using York, Pennsylvania as a case study area, to ascertain an optimum reservoir storage which would minimize the economic risk (expected yearly regional losses) of a water supply shortage, is given in this report.

After the simulation technique is developed, it is possible to determine which costs, decisions or system failures contributed the most to the total economic effect of the shortage. This is done by a direct analysis of the data and the use of a sensitivity analysis.

In selecting the areas to be studied, it was the original intention to survey three communities that had experienced water shortage conditions during 1966. Mainly on the basis of drought severity information for that year provided by the Environmental Science Services Administration of the U. S. Department of Commerce, a number of communities were selected where drought appeared to have been a major problem. Waterworks officials were contacted by telephone in 40 of such communities, but most of them stated that they had encountered no real water shortage during that period, or at worst had "muddled through" without much difficulty. The obvious conclusions from such a response were that meteorologic drought does not necessarily reflect a water shortage situation in any given community or that the water managers did not want to admit that a shortage situation had arisen. However, a few of the managers admitted to actual shortage conditions of varying degrees, and of this group three were selected for further study - York and West Chester, Pennsylvania, and Harrisonburg, Virginia. Conferences were held with the water managers of each of these communities and it was finally decided to concentrate our efforts on York, Pennsylvania. This decision was made largely because:

1. The York area contained a population of over 100,000 and had a good "mix" of residential, commercial and industrial customers;
2. The York Water Company had excellent daily records of water supplies and demands during the 1966 shortage period;
3. The company actually instituted voluntary and then mandatory water restriction controls on its customers; and

4. The management of the water company and most of its large water-using customers were very willing to cooperate in providing much of the basic information required for this study.

The data and other information obtained from this area, therefore, provides in large part the basic inputs for the analysis described in the following chapters. Analysis of the large body of data from York enabled the methodology to be developed. In the future other areas can be studied because the methodology can be applied to data-sparse cases using the estimates with which regional planners are familiar.

A map of the York area showing the territory served by The York Water Company and the creeks and reservoirs of the supply system is shown in Figure 1-2. The boundary shown on Figure 1-2 delimits the service area of the Company and is assumed to be the regional boundary. A regional viewpoint is taken in this study which directs attention to drought effects which are transmitted across the regional boundary.

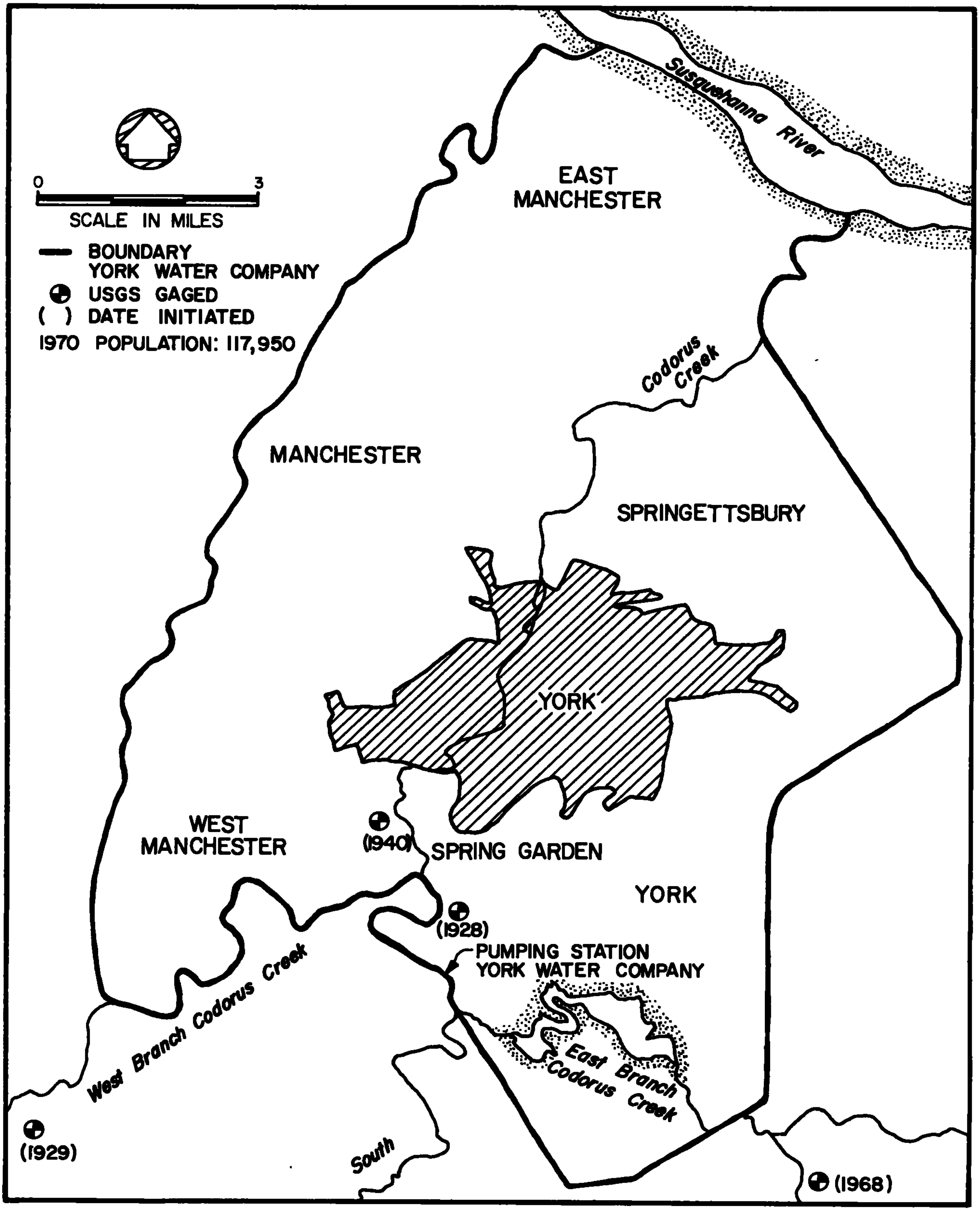


FIGURE 1-2
STUDY AREA

2. CONCLUSIONS AND RECOMMENDATIONS

The conclusions are of two types: general and specific. General conclusions relate to the utility of the general methodology for application elsewhere. Specific conclusions relate to the conditions and measurements associated with the York, Pennsylvania case study. Inductive reasoning processes form the basis of this study; the specifics of the York situation pointed toward the construction of the general approach. Recommendations are oriented toward future directions which appear to be promising. Research and analysis on the effects of water shortage, particularly risks, is a relatively new endeavor and one which should yield high rewards in terms of efficient resource allocation.

GENERAL CONCLUSIONS

1. An encompassing definition of water shortage, which serves analysis needs, is: *any time the water purveyor chooses, or is forced into, a position where he cannot supply the total demand for water in the system.*

2. Risks, which are the result of water shortage, can be measured on a regional basis. Risks are defined as the expected value of annual regional losses. Regional losses are dollars which flow out of a region to external interests because of water shortage conditions within the region.

3. The general approach for conducting a risk analysis follows the logic shown in Figure 2-1.

4. Central to a risk analysis is the local water manager. He must supply municipal data and direct the analysis effort toward heavy water users and water sensitive industries.

5. Water shortage induced economic losses can be estimated for four sectors: municipal, domestic, industrial and commercial, which is convenient for analysis purposes. A subdivision is required for the industrial sector: locally owned industries and externally owned industries operating within the region.

6. Definition of industrial losses requires a two step process:

a. using an interview to relate production cut-backs to water shortages, and

b. gathering economic data such as payrolls, wages and value of shipments, from secondary sources to infer losses.

7. An analysis which keeps a day to day accounting of water allocations and regional losses is required. This analysis is most conveniently done using computer simulation.

8. The methodology developed herein can be applied to other regions, similar to York, Pennsylvania, for an effort expenditure of four to six man-months.

SPECIFIC CONCLUSIONS

1. The losses attributable to the 1966 drought in York, Pennsylvania are estimated as (refer to Chapter 5 for complete cost breakdown):

	TOTAL	REGIONAL
a. municipal	$570,000	$ 54,000
b. domestic	544,000	125,000
c. industrial	140,000	none
d. commercial	30,000	30,000
	REGIONAL TOTAL	$209,000

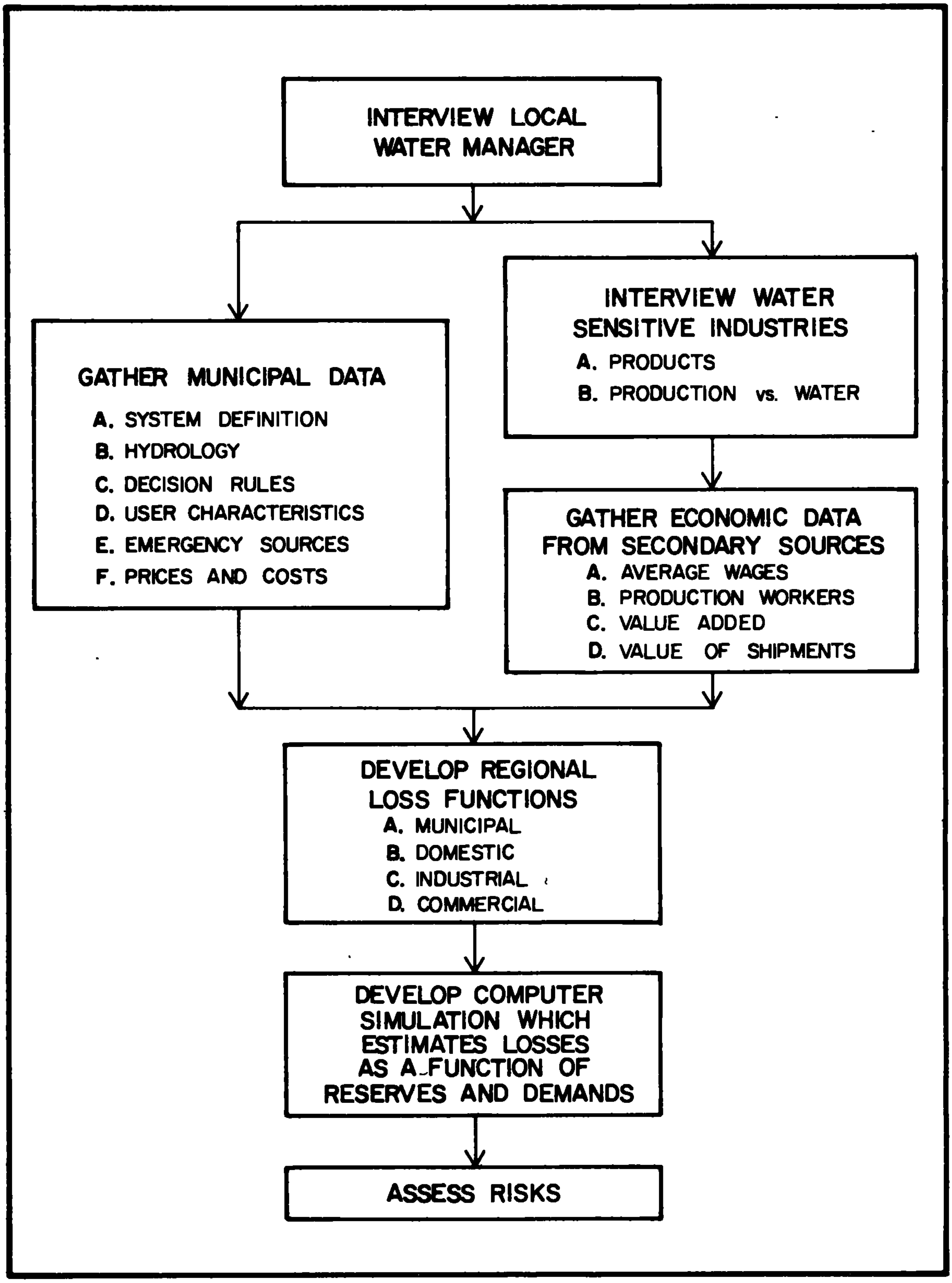


FIGURE 2-1
GENERAL APPROACH

The total losses represent sector transactions, some of which may flow within the region. Regional losses represent the dollar flows outside the region and are included in the sector totals. Summer streamflows, lower than those observed in 1966, have an annual probability of .04; the occurrence of regional losses equal to or greater than $209,000 have the same probability.

2. The expected or average loss, which is the risk, for 1966 conditions is $32,000. The fact that the actual loss is higher than the risk attests to the severity of the 1966 drought.

3. The major components of risk which account for three-quarters of the total loss are those associated with externally owned industry. These risks are borne by the water company (lost revenue) and the local workers (lost payroll).

4. The contributions to total risk from importing of emergency water, loss to local industries and loss of consumer surplus are nearly equal; the risk of regional stock losses is negligible for York.

5. The citizens of York responded in a sympathetic and helpful manner to water company appeals to reduce usage; demands were voluntarily reduced during the 1966 drought.

6. Industrial managers were helpful and divulged most of the information needed to directly estimate losses, but would not divulge information relating to payrolls or profits.

7. In 1972, after the completion of additional reservoir capacity, the level of regional risk in York is about $40,000 per year; thus, the yearly risk is about 30 cents per capita. Reduction of this risk to $20,000 would require an additional 750 million gallons of storage.

8. Major factors listed in their order of importance for assessing the York risk are: per capita demand, streamflow, interest rate, industrial losses, population, import costs, domestic losses and the water manager's decision schedule. This ranking is based on a sensitivity analysis of each factor's individual impact on estimated risk.

RECOMMENDATIONS

The overall recommendation arising from this work is that risks should be assessed and incorporated within the framework of water resource studies. The experience gained from the conduct of the study gave rise to many interesting ideas that yield avenues for future research. The most important recommendations, which incorporated into additional studies would provide information for advancing the understanding of the water shortage phenomena, are the following:

1. A more generalized knowledge of loss functions and acceptable risk levels should be developed by performing additional case studies.

2. An analysis could be done using existing techniques, such as linear and dynamic programming, to evaluate the optimum procedure a water manager should follow to minimize losses due to a water supply shortage.

3. A better knowledge of the price-demand relationships for water under varying conditions is needed.

4. Hydrologic drought has two components, magnitude and duration. An analysis that incorporates the probabilities and effects of both these components would better define a shortage condition.

5. A shortage situation could possibly be avoided by making temporary use of poorer quality supplies. Under shortage conditions many of the large water-using industries could accept process or cooling water which was not of acceptable drinking quality; this would significantly reduce the demand on the normal source of supply.

6. The techniques developed in this study could be used to study the economic effects of water supply shortage from different viewpoints instead of the overall regional viewpoint now taken. For example, taking a residential customer's viewpoint, the actions that would minimize the residential losses are not the same as minimizing the total regional losses. Likewise, the objectives of the water manager are not likely to match regional objectives; he is not as concerned with losses in other sectors as he is

with his own loss, namely the emergency expenses and import costs. Different optimum solutions to the shortage problem exist depending on the viewpoint analyzed.

7. The relative importance of secondary (or multiplier) economic effects as they pertain to regional loss accumulation should be assessed.

3. METHODOLOGY

The objective of this chapter is to present the general approach and overall framework of risk analysis as it applies to water shortages. Details of the various components of the analysis are given in the other chapters of this report. Thus, this chapter is intended to give the overall perspective of the procedures and their step-by-step components. The topics, in their order of presentation, include risks, analysis logic, and implementation.

RISKS

Consider a set of drought situations, each one of which is of different severity and all of which span a range of drought conditions. For a given drought situation economic losses are postulated. Each drought situation is assigned an annual probability of occurrence and has an economic loss associated with it. Thus, a set of possible drought conditions and their associated losses are graded such that incipient drought and catastrophic drought represent extremes and the remainder of the set are in between the extremes. *Risk* is the expected value of the loss which is the sum of the products of the probabilities and their respective losses. *Risk avoidance* can be construed to be a measurement of the benefits associated with the reduction of supply fluctuation. The risks, of course, are associated with the short run and continuing losses. This risk study is not intended to measure benefits although risk analysis can be integrated into regional economic studies. If benefit schedules can be associated with demand schedules, a regional objective would be to determine those demand schedules and water supply facilities which maximize the benefit minus the sum of the cost plus risk.

However, it is emphasized that in this study the general technique for loss evaluation is through a requirements approach. Demands are assumed given. If demands are not satisfied, losses are assumed to occur. The risk of such losses is their expected value.

Surface water supply systems are the focus of this report. For such systems, storage reservoirs provide the water reserves which mitigate against shortages. As the amount of storage in a system increases the risks decrease, everything else remaining the same.

The general level of economic activity in a region is partially reflected in the regional water demands. As the requirements for water increase, the economic losses associated with not meeting the requirements increase. Thus, as the demands increase, the risks increase.

Consider a boundary which surrounds the region under study to determine risks. Droughts are presumed to cause economic losses to various segments of the economic system within the perimeter. Other segments gain as the wealth is transferred. Within the boundary these exchanges are self canceling. A regional viewpoint is taken herein. Losses which flow across the boundary, and out of the region, are estimated and used to compute the risks.

Figure 3-1 shows the relationship between yearly risk, storage and demand for York, Pennsylvania. Note that risks decrease with increasing storage and increase with increasing demand. Such results can be used to balance resource development decisions (storage levels) versus economic development decisions (demand levels).

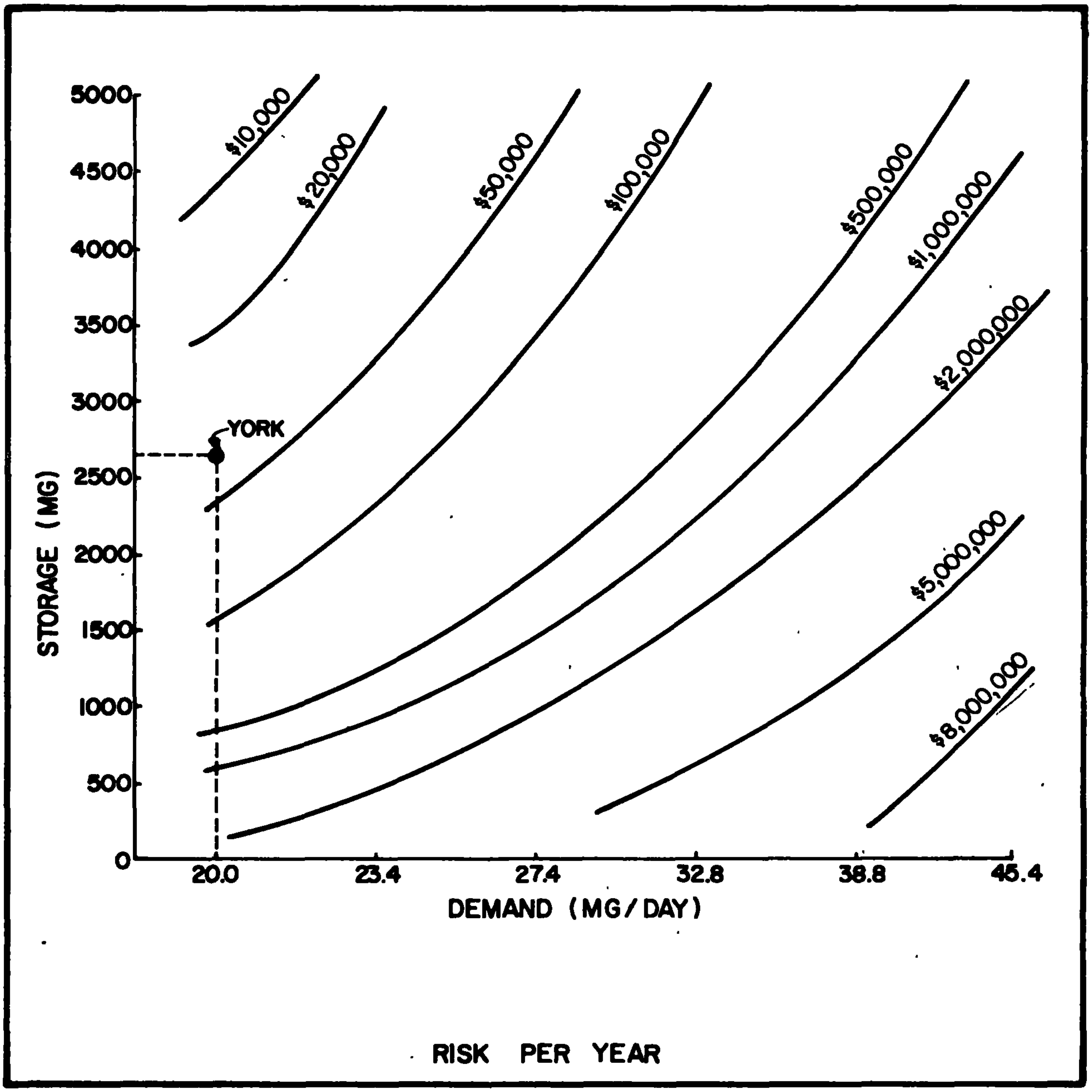


FIGURE 3-1
MAJOR RISK RELATIONSHIPS

ANALYSIS LOGIC

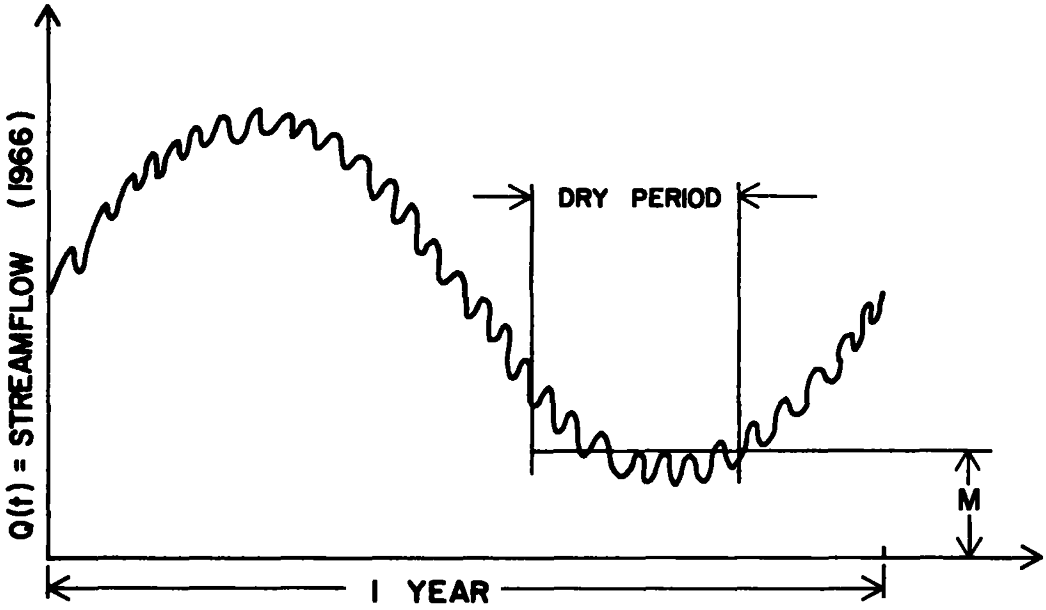
The logical cornerstone is the definition of shortage adopted herein. Namely, a water supply shortage occurs *any time the water purveyor chooses, or is forced into, a position where he cannot supply the total demand for water in the system.* Clearly, this places the water manager in the center of the analysis; the actions he takes start a chain of events, the economic consequences of which are measured and analyzed.

Analysis then, to be in harmony with the shortage definition, is of short-run events associated with not meeting requirements. Shortage can be caused by drought, inadequate reserves, or the policies of the water manager; to name only a few of the possible causes. However, if the shortage is chronic or lasts too long or carries too high an economic penalty, that is, if the situation is too *risky,* then long-run changes are initiated. Such changes could be the construction of a new reservoir, the restriction of regional growth, an increase in price, or a change in management approach.

To measure risks, the approach taken is to perform a day-by-day analysis of how water is transferred and stored within a regional system. The supply of water and its distribution is a hydrologic problem. Transfer, storage, and distribution of water are controlled by the water manager. Economic losses occur as distribution is curtailed to various segments of the region. The major elements of the analysis, then, are the hydrology, demand contraction assumptions, actions of the water manager, and economic losses.

Hydrology

The term hydrology implies the estimation of daily streamflow inputs to the supply system. A year with a low flow period is selected. The year



SIMULATION INPUT

m = MEAN HAVING A KNOWN PROBABILITY (P)

M = 1966 JUNE, JULY, AUGUST AND SEPTEMBER MEAN (32 CFS)

$$\text{INPUT} = \frac{m}{M} Q(t)$$

FIGURE 3-2

HYDROLOGY

may correspond to a period of known economic stress associated with the dry period. For the eastern United States the June through September period is normally the period with lowest streamflows.

A defensible strategy is to select streamflow data whose mean flow for the June through September period is the lowest of record. These daily streamflow data are adjusted up and down to correspond to various probability levels according to the scheme shown in Figure 3-2.

The following two conditions are assumed:

1. The resultant daily flow data correspond to input to the reservoir or supply system, since gages are seldom located at this point, data adjustment is called for, and
2. The reservoir is full at the start of the dry period (for example, June 1); thus, shortages carried over from year to year are beyond the scope of this study.

Demand Contraction

Under normal circumstances, supply equals demand. Demand, of course, may be established by pricing or by custom as in the case of the flat rate user. In shortage circumstances, supply is forced to be less than demand by actions of the water manager. A five-step order of cut-back is postulated as shown in Figure 3-3. This cut-back scheme is based on logic, experience and knowledge that domestic water consumption is considered to be the highest priority use of water. Briefly, the five steps are :

Directed At All Users

1. Voluntary cut-backs accomplished by public appeals,
2. Mandatory cut-backs associated with elimination of the outside use of the hose,

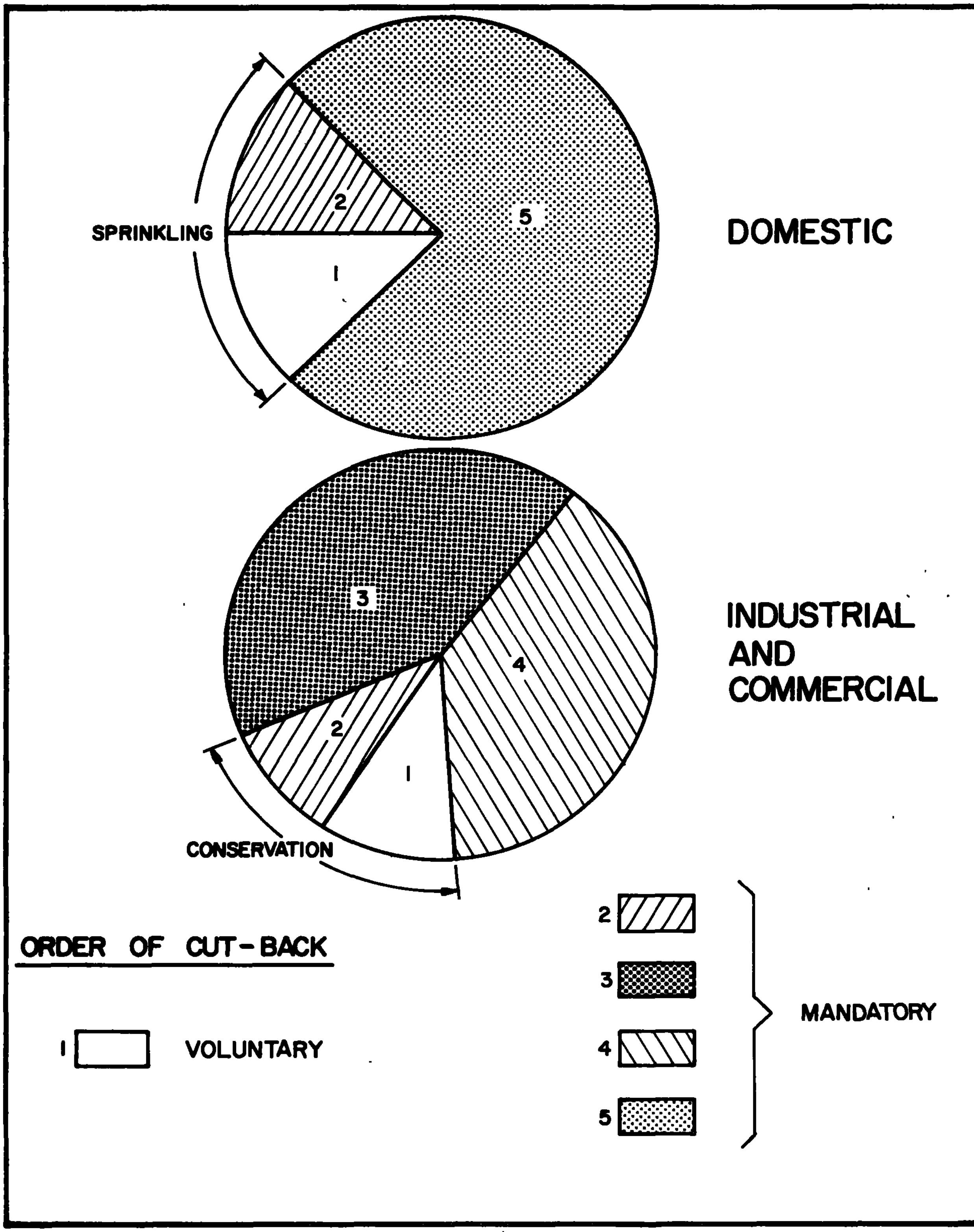


FIGURE 3-3
DEMAND CONTRACTION

Directed At
Industrial and Commercial Users

3. Mandatory 50% cut-back of the amount used inside each establishment,
4. Mandatory shut-down of all industrial and commercial usage, and

Directed At Domestic Users

5. Mandatory severe (but not total) restrictions of the water usage inside homes.

Steps 1 and 2 are based on the experience of York, Pennsylvania Step 5, the last demand contraction, is based on the concept that domestic water use is the most privileged. Steps 3 and 4 are postulated intermediate demand contractions.

Water Manager Actions

The policies of the water manager regulate the system and dominate the entire day-by-day analysis. He monitors streamflow and reserves and makes supply allocations. He also can purchase water from other sources. Figure 3-4 shows the central position of the water manager.

It should be recognized that different water managers follow different decision schedules. Some, who utilize large rivers may base their decisions only on streamflow. Others, who utilize protected watersheds and large reservoirs may consider only the amount of water in storage. A combination of flow and storage is also possible. Each situation is expected to be different. However, a main premise is that the policies can be defined.

The decision schedules for York, Pennsylvania are based on storage levels in their reservoirs. The water manager monitors these levels and

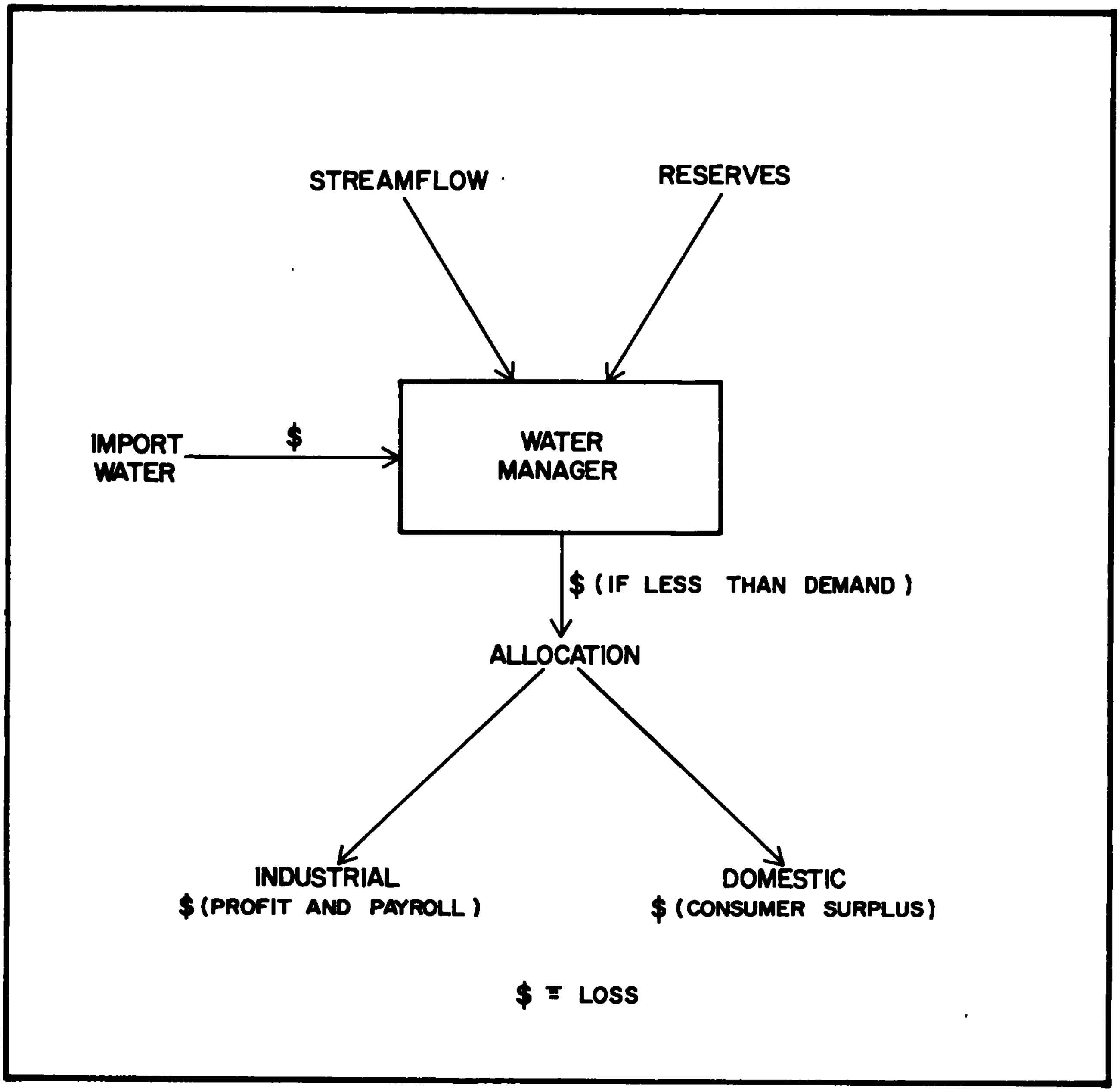


FIGURE 3-4
CENTRAL POSITION OF WATER MANAGER

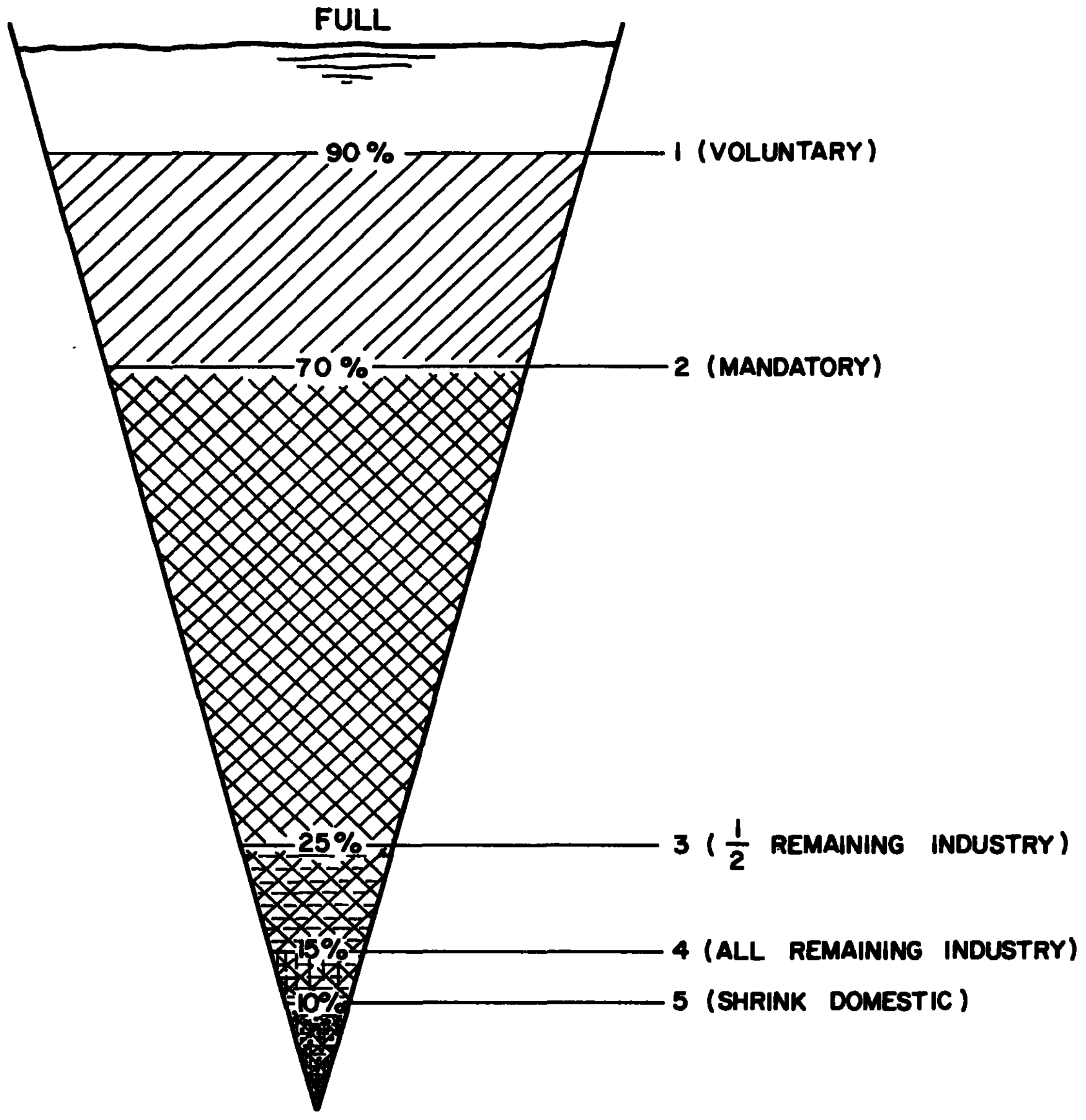
takes specific actions at various storage levels. These actions are either directed at demand contraction, as shown in Figure 3-5, or at securing outside sources of water, as shown in Figure 3-6. The costs shown in Figure 3-6 are those actually encountered by The York Water Company in 1966. These decision schedules are based on observed behaviors, interviews with the water manager during which situations which have not been experienced are discussed, and judgment.

For both Figures 3-5 and 3-6 reservoir levels less than 25% of full have not been encountered in York; thus, decisions associated with the occurrence of very low reservoir levels are speculative. Such decisions are specified to complete the set of possible conditions in order to conduct a comprehensive analysis.

Economic Losses

The combined effects of the hydrology, actions of the water manager, and the demand contraction cause economic losses to occur. These losses are accounted for on a day-by-day basis.

To estimate shortage induced losses it is useful to trace the shortage induced flows of economic goods and services within a municipality or metropolitan region. Such a procedure may not be complete with respect to all significant flows that may be induced by a shortage that affects any particular city, but it does suggest a systematic process for determining the impact of economic losses on four sectors within an area; namely, the municipal government, commercial, industrial and domestic sectors. At the local decision-making level differential impacts on the four sectors may be significant, and therefore separate loss accounts, one for each sector, may be important. Furthermore, in deriving an aggregate regional drought loss function for the area, it is important to identify those losses to each sector which are simply intersector shifts



NOTE: SEE FIGURE 3-3 WHICH ILLUSTRATES DEMAND CONTRACTION

FIGURE 3-5

RELATION OF DEMAND CONTRACTION TO RESERVE LEVELS

of goods and services, and to exclude them from aggregation. These shifts do not contribute to the aggregate loss function.

A flow diagram for intersector flows and other drought losses is shown in Figure 3-7. The minimal aggregation level represented in the diagram is that of sector totals. To be sure, there are flows within sectors. While it is conceivable that in some instances it may be necessary to disaggregate all sectors, it would seem that in general the single most important disaggregation required in all analyses is to separate the industrial sector into subsectors, locally owned and externally owned. This distinction is especially important in estimating short run drought losses because drought losses incurred by locally owned enterprises represent a real loss of wealth to those concerns. Drought losses incurred by externally owned industry are absorbed by external interests and the real associated losses to the object area are measured by the payroll losses incurred by the domestic sector, which is ordinarily employed by these industries.

In order to design loss estimation procedures, the intersector losses for the York case study were examined in detail. In general, it is thought that major regional losses will fall into the six categories shown in Figure 3-8, which is a simplification of Figure 3-7. For the purpose of regional risk estimation for York, five of these six categories were considered; stock losses were excluded because most stock adjustments were inter-regional.

Industrial losses are the most challenging to estimate. Water sensitive industries are identified. Production is related to water availability in accordance with discussions with industrial plant managers. Payrolls, profits and fixed costs are related to production using published sources of information.

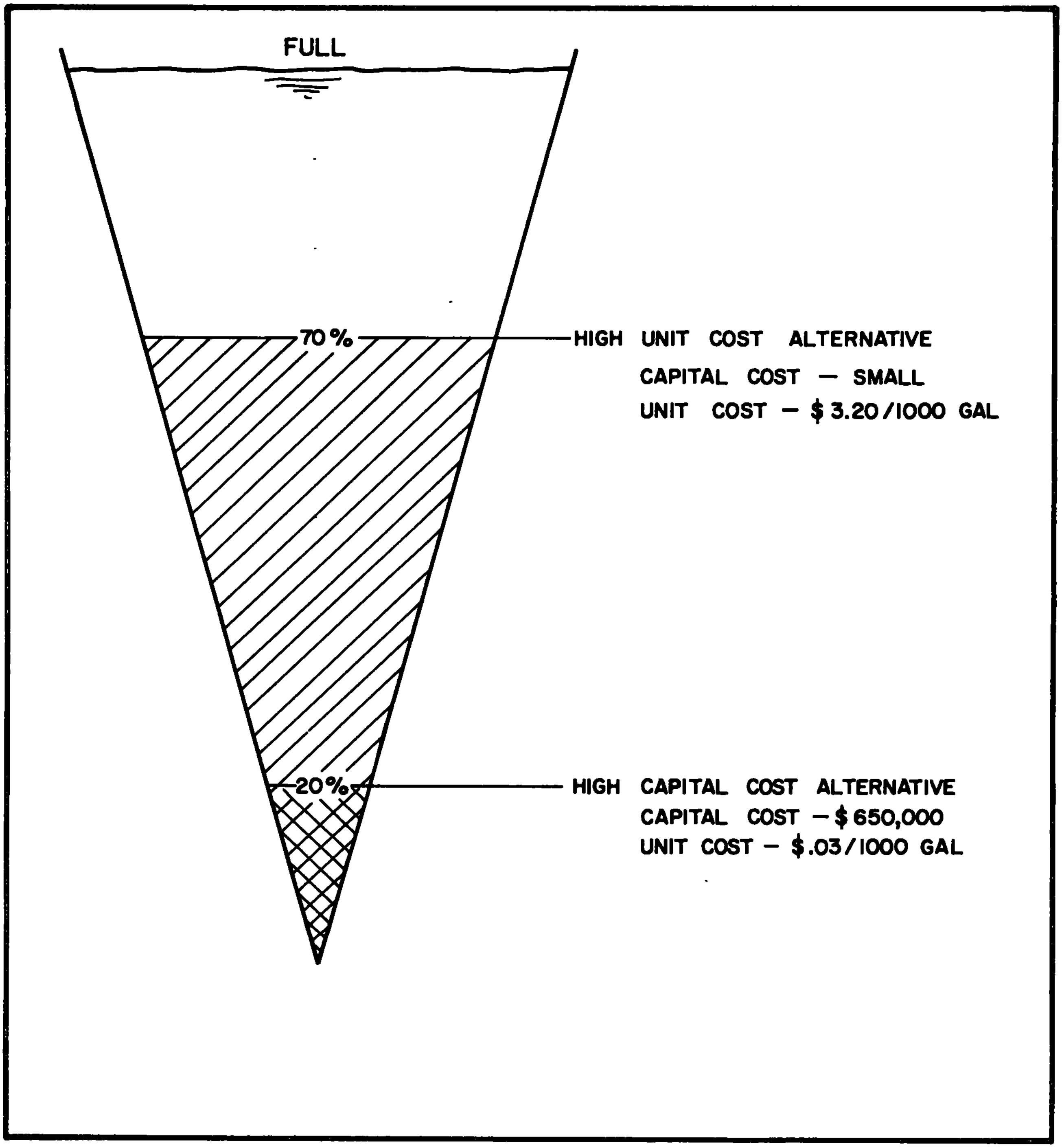


FIGURE 3-6
EMERGENCY SHORT
RUN SOURCES vs. RESERVES

IMPLEMENTATION

This section discusses the major components of a risk analysis. These include the data gathering approach and the general attributes of simulation logic.

The starting point for acquiring information for a risk study is the water manager. Initial efforts focus upon him. The entire process of data acquisition and analysis is comprised of four steps.

1. Interview the water manager and maintain liaison with him. Of interest are his identification of large water-using industries (water sensitive industries), his decision schedules which are imposed in the face of shortage, and his records. The records include engineering definition of the system, demand data, pricing schedules, operating cost information and user characteristics.
2. Gather and process daily streamflow data. A period of drought and a knowledge of system operations, formed in Step 1, can be used to check water balance computations. These flow data may come from water company files or from U. S. Geological Survey publications.
3. Interview the plant manager or plant engineers of water sensitive industries. Industrial response in terms of production levels versus intake water is to be determined by interview questions. Questions should be phrased in such a way that disclosure of competitive information such as wage levels and value of shipments is avoided. Specifically, it must be determined to what extent production in each plant would probably be cut back for each of various levels of water restriction. Firms offer estimates on this point but are reluctant to estimate the extent to which the number of production workers would have to be reduced. In other words, the idea is to acquire enough plant operating information in order that the interview data can be blended with economic data from secondary sources to derive loss data.
4. Acquire and analyze secondary sources of economic data. Industry norms which are keyed to the Standard Industrial Classification (SIC) codes of the U. S. Bureau of the Census are derived. The basic source of information is the 1967 Census of Manufactures, supported by other data obtained from the Statistical

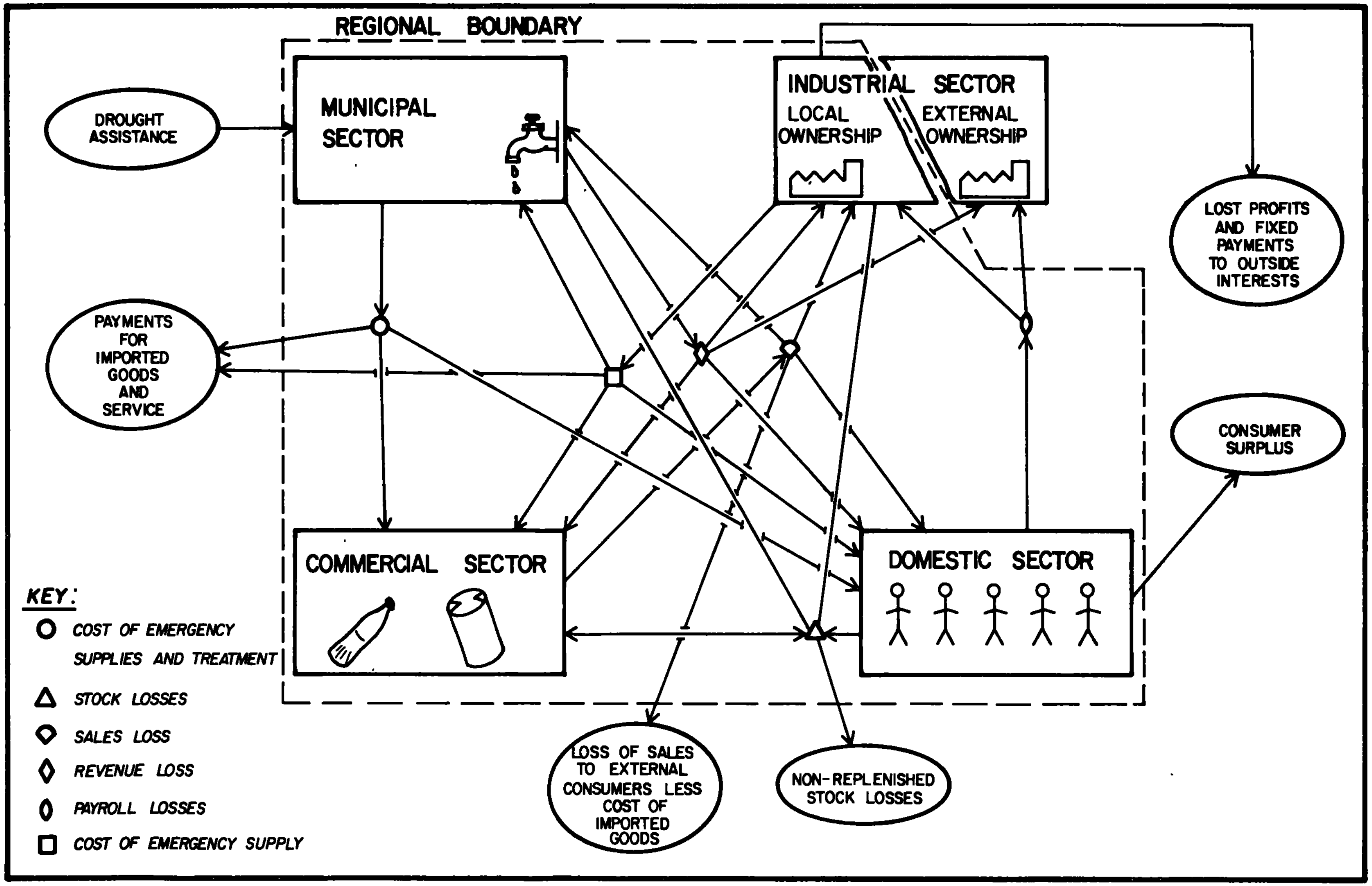


FIGURE 3-7
WATER SHORTAGE LOSS BALANCE

Abstract of the United States. Using such secondary data, economic production data can be placed on a per worker basis. For example, wages per worker in a particular SIC industry can be derived. Data on numbers of production workers in each plant are generally available from state industrial or workmens compensation commissions, if not from the industrial firm itself. A further secondary source of data is the functional form which represents domestic water demand (sprinkling and household); such a function is fit to the regional demand data obtained in Step 1.

Data from the four steps are used to:

1. Describe the physical characteristics of the reservoir and distribution systems,
2. Disaggregate demand into the various sectors and describe regional demand build-up as a function of time,
3. Identify and price sources used for emergency water supply,
4. Specify the water manager's decision schedule,
5. Fit domestic price-demand functions, and
6. Derive industrial loss functions for two sub-categories: locally owned and externally owned.

The details of these data gathering and analysis activities are described in subsequent chapters. The ultimate usage of the data is in a simulation model which computes the regional water losses for a given four-month period of daily streamflow input.

The simulation model uses the following two step logical progression:

1. The daily streamflows are routed on a day-by-day basis through the various demand sectors in accordance with the water manager's decision schedule. As the available supply of water becomes critical, the supply is restricted to be less than demand and additional emergency sources are tapped. The daily allocations of water govern the economic response;
2. A loss calculation is performed based upon the daily allocations of water. As supply is constricted, losses are incurred; these losses are tallied by the various sectors and are accumulated to estimate the regional loss.

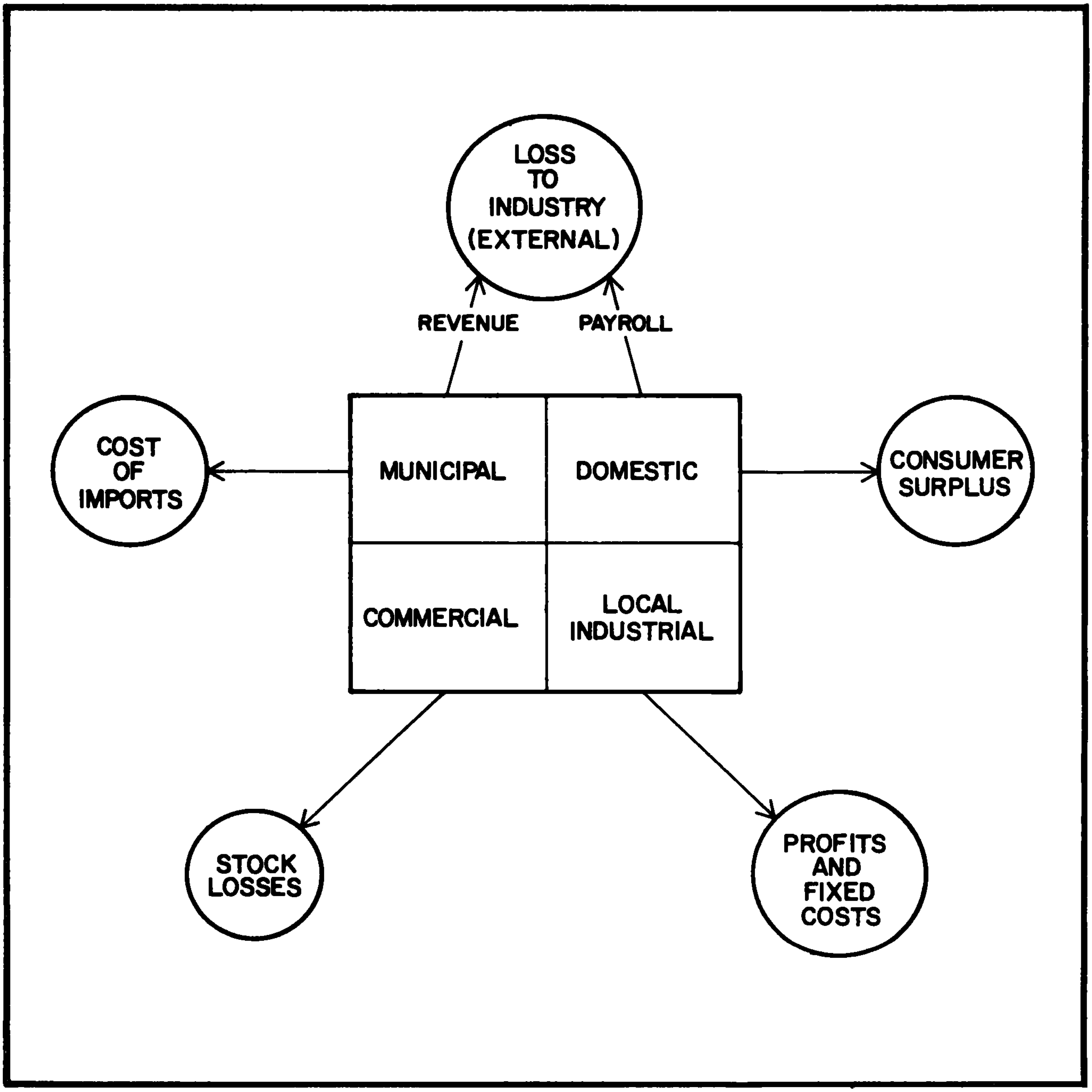


FIGURE 3-8

PRINCIPAL LOSS ELEMENTS

Important points concerning the model are that is is designed using daily time increment and that it is designed for flexibility. Furthermore, it should be cost effective to use. Each seasonal computation should not be too expensive, as numerous computations are required. Flexibility is a necessary attribute for sensitivity testing to assess the importance of various loss components.

Recall that a number of different daily flow traces, each having an annual probability of occurrence, are used in the analysis. Each trace is operated upon by the model and the loss is computed. The loss associated with each trace is multiplied by the appropriate probability and the products are summed to derive the *risk*, the expected value of the loss.

What manpower resources and skills are required to conduct a regional shortage risk analysis? Three areas of competence dominate: water resources engineering, economics, and computer programming. The analysis group should contain large measures of these competency areas. A rough estimate of the level of effort required to conduct an analysis on an area approximately the same size as York is 4 to 6 man-months.

Two time consuming tasks are involved: the interviewing of plant managers and the coding of the simulation model. Interviewing time will vary as the number of water sensitive industries in a region. Also, the degree of cooperation and willingness to provide information is expected to vary from region to region. It is recommended that the existing computer code be revised for each new study; the rationale for this conclusion arises from the facts that water managers' decisions are expected to vary and that each region's characteristics are unique.

4. BASIC DATA

Several sources of information were used to obtain the required data for this study. Some were provided by The York Water Company, others by official government sources, by manufacturing firms, by industrial associations, and finally by individuals that had actually experienced the 1966 water shortage.

The actual kinds of data required were:

1. Geographic - primarily topographic maps of the York, Pennsylvania area,
2. Hydrographic - mainly streamflow records, drainage areas, etc.
3. Operational - the daily total demand and supply data, including reservoir levels of the water company, plus data on the number, location, rate classes and consumptions of its several classes of customers,
4. Demographic - population growth and distribution,
5. Economic - mainly number of production workers and payrolls, value added by manufacturing (in the large water-using industries), value of homes, size of residential properties, etc.
6. Psychological - primarily the responses of various classes of customers to the water shortage.

DATA SOURCES

The following sources provided the above and other basic data used in this study:

1. The York Water Company

   The company had excellent records on:

   a. daily pumping demands,

   b. daily reservoir levels,

   c. monthly consumption and revenues by various classes of customers,

d. names and annual consumption of the company's largest customers,

e. itemized costs to the company of the 1966 water shortage,

f. projected population of the York area, and

g. projected per capita consumption.

2. U. S. Government Agencies

a. U. S. Geological Survey - mainly topographic maps and streamflow records and drainage areas as published in "Surface Water Supply of the United States,"

b. Bureau of the Census - figures on production workers, man-hours, wages, value added by manufacture, cost of materials, value of shipments and industrial water consumption as published in the "1967 Census of Manufactures, Pennsylvania." Also population data as published in the "1970 Census of Population" and residential property values as published in the "1970 Census of Housing."

c. Corps of Engineers - reservoir cost data as published in the Potomac River Basin Report, submitted to the House of Representatives Committee on Public Works on June 1, 1970 and referred to as House Document No. 91-343.

3. Commonwealth of Pennsylvania Agencies

a. Bureau of Statistics - data on the average number of employees at specific production plants in 1966.

4. County and Local Agencies

a. Manufacturers' Association of York, Pennsylvania - information on whether ownership control of firm was exercised in York, or outside the region, e.g., plants in York that are subsidiaries or divisions of large industrial firms with headquarters in other cities were considered to have outside ownership.

b. York County Planning Commission - economic analysis data on manufacturing activity in the York area.

5. Interviews

a. Industrial firms - these were personal interviews, usually with the vice president for engineering or the plant engineer to determine primarily:

1. what specific actions were taken during the 1966 water shortage (digging wells, trucking in water, installing recirculating equipment, etc.),
2. when such actions were taken,
3. whether they were voluntary or mandatory,
4. about what percentage of intake water was saved in so doing,
5. the total cost of such actions, and
6. what actions the company would be likely to take in the future if water supplies are reduced by 10%, 20%, 30%, 40%, 50%, or 100%. (Actually, to what extent would the company have to curtail production).

Note: Not all of the above information was obtained from each industrial firm, but in total, a substantial amount was provided to present a fairly accurate picture of the responses of industry to the water shortage period.

b. Others

Other interviews were held with:

1. commercial car wash establishments that were subjected to severe mandatory controls in the summer of 1966;
2. well drillers who were quite active during the period,
3. quarry owners who provided supplementary supplies of water to The York Water Company,
4. nursery companies,
5. a country club that had to restrict watering,
6. the Mayor of York, a medical doctor who was head of the Health Department in 1966, and very concerned at that time with water quality,
7. the Fire Chief of York who had devised a fairly comprehensive plan for adequate water supplies in the event of an outbreak of fires during the shortage period.
8. the head of the York Public Works Department in 1966,
9. the York Dispatch and York Daily Record that reported developments as they occurred, especially statements of

the water company, reactions of customers, and meetings held by interested parties.

6. Questionnaire

The York Water Company mailed a questionnaire to all of its residential metered customers and almost half of its residential flat rate customers to determine:

a. what degree of inconvenience (major, minor, or none) each experienced during the shortage period;

b. what financial loss, if any, did each suffer;

c. if a loss was suffered, was it to lawns and shrubs or "other;"

d. which of the following water uses, and in what order, did each customer restrict his use during the shortage period:

   1. car washing,

   2. dishwashing,

   3. laundry,

   4. lawn sprinkling,

   5. toilets, and

   6. tub or shower.

5. DROUGHT RESPONSE

As previously stated, York, Pennsylvania was selected as the subject for this case study to determine the economic risks that were encountered within a specific area that actually experienced a water supply shortage. The search for such an area began with information obtained from the Environmental Data Service of the U. S. Department of Commerce. As shown in Figure 5-1, very extreme drought conditions occurred during the summer of 1966 in the south-central and southeastern regions of Pennsylvania and in the western sections of Maryland and Virginia. York is centrally located within this region.

In addition to information from the York area, useful drought data were obtained from both Harrisonburg, Virginia and West Chester, Pennsylvania, which are discussed in this chapter.

DESCRIPTION OF THE YORK AREA

The City of York, the county seat of York County, is the central and largest community of a fairly prosperous area in the south-central part of Pennsylvania, roughly 15 miles north of the Pennsylvania-Maryland line on Interstate Highway 83. The city is situated on Codorus Creek, which flows in a northeasterly direction where it joins the Susquehanna River, approximately 10 miles downstream. The area served by The York Water Company, with York as its center, extends approximately nine miles east and west and 11 miles north and south. A map of the York area showing the territory served by The York Water Company and the creeks and reservoirs of the supply system is shown in Figure 1-2.

The water company is a privately owned enterprise rather than a municipally owned and controlled utility and is now in its 156th year of operation. The company serves not only the City of York, but several contiguous townships and boroughs as well, all in York County. The total population of the area served by the water company in 1966 was 113,000, approximately 56,000 of whom lived in the City of York. At that time the company had approximately 30,000 residential customers, 1900 commercial and 350 industrial customers.

In 1963 income derived from manufacturing activities consituted the largest single component of personal income. At that time it represented 35.0% of the total for York County. Wholesale and retail trade, public utilities, and construction constituted another 24%, with the result that more than half of the personal income in the area is dependent on industrial and other commercial activities.

Manufacturing continued to be the driving force behind the economy in the York area in the 1960's. Furthermore, most of the manufacturing activity in York County was carried on in York and the other municipalities served by The York Water Company. As shown in Table 5-1, over half of the manufacturing establishments which employed two-thirds of the industrial labor force in York County in 1966 were served by the company. Wages and salaries, value added by manufacturing, and value of shipments for the industrial establishments served by the water company each represented over 70% of the totals for the entire county.

Compared to most manufacturing centers, York County has a remarkably diverse manufacturing complex, amounting to 20 separate Standard Industrial Classifications (SIC's), as shown in Table 5-2; this table ranks SIC sectors by total value of shipments. Furthermore, most of the large water using industrial firms in York are included in the seven highest ranked SIC classes; this group represents 70% of the total value of industrial shipments in York County.

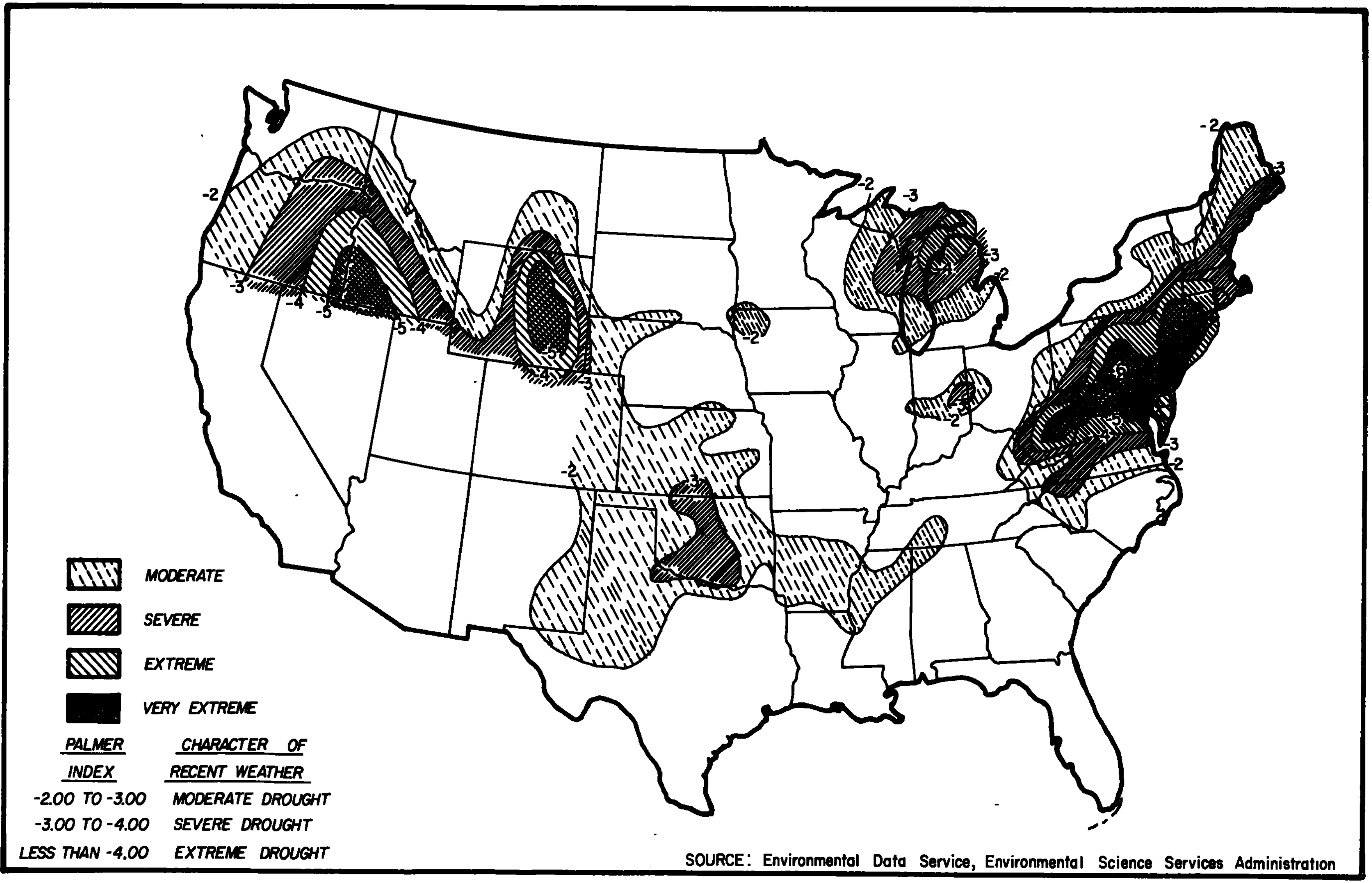


FIGURE 5-1
MAXIMUM DROUGHT SEVERITY MAY 1 TO OCTOBER 31, 1966

TABLE 5-1 Manufacturing Activities in York County Municipalities 1966

Municipality Served By The York Water Co.	Number of Establishments	Total Number of Employees	Wages and Salaries (in $1,000)	Value Added By Manufacture (in $1,000)	Value of Shipments (in $1,000)
York City	193	14,934	$ 82,789	$164,685	$ 287,417
Spring Garden Township	31	6,905	46,212	87,713	164,125
Springettsbury Township	17	5,126	38,742	64,598	126,416
West Manchester Township	24	3,293	21,821	47,472	110,958
West York Borough	22	1,181	6,682	12,224	21,614
Manchester Township	21	879	4,651	11,781	24,932
North York Borough	11	594	3,610	5,925	11,770
Mount Wolf Borough	5	608	2,928	4,463	8,243
York Township	12	235	1,282	2,338	4,038
Jacobus Borough	3	179	748	1,521	3,312
Sub-Total	339	33,934	$209,465	$402,720	$ 762,825
All Other York County Municipalities	309	16,828	81,065	161,793	316,693
Total	648	50,762	$290,530	$564,513	$1,079,518
% of The York Water Co. Municipalities To All York County Municipalities	52.3%	66.8%	72.1%	71.3%	70.7%

Source: 1966 County Industrial Report, York County and York County Planning Commission.

TABLE 5-2 Diversification of Manufacturing Activity in York County (Based on Rank Order of Value of Shipments) 1965

SIC Class	Kind of Products	% of Total Value of Shipments	Cumulated %
35	Machinery Except Electrical	18.5	18.5
34	Fabricated Metal	12.1	30.6
20	Food and Kindred Products	11.1	41.7
26	Paper and Allied Products	8.4	50.1
36	Electrical Machinery	7.3	57.4
25	Furniture and Fixtures	7.3	64.7
19	Ordnance and Accessories	6.2	70.9
22	Textile Mill Products	4.6	75.5
27	Printing, Publishing	4.1	79.6
28	Chemicals and Allied Products	3.6	82.2
31	Leather and Leather Products	3.0	85.2
23	Apparel	2.8	88.0
33	Primary Metals	2.4	90.4
21	Tobacco	1.9	92.3
38	Instruments	1.8	94.1
37	Transportation and Equipment	1.4	95.5
29	Petroleum and Coal	1.2	96.7
24	Lumber and Wood Products	1.0	97.7
39	Miscellaneous	1.9	98.6
30	Rubber	0.8	99.4
	Other	.6	100.0

Source: York County Economic Analysis, Volume II, Manufacturing, by The York County Planning Commission.

HISTORY OF THE 1966 YORK WATER SHORTAGE

Precipitation in the York area had been below average for each of the four years previous to the 1966 shortage. Moreover, light snowfalls and abnormally cold weather during both the winters of 1964-65 and 1965-66 caused ground freezing to considerable depths, resulting in high runoffs and low infiltration to ground waters.

As a result of these developments, officials of The York Water Company became apprehensive in January of 1966 of an impending water shortage. On February 14th the General Manager of the water company brought this matter to the attention of the Board of Directors.

Rainfall during January and February of 1966 was above normal, but because of the ground freezing there was also above normal runoff. Total precipitation in March, April and May of 1966 was about 25% below normal. In June there was practically no rain and temperatures were well above normal. Water consumption, especially by residential customers, was increasing sharply. By June 13th the Codorus Creek flow at the company's pumping station was so low that sustained drawdowns of the reservoir were begun.

Conditions worsened through June and into July. On July 7th, when demands had reached a near-record level of 25.7 million gallons per day (MGD), the company asked its customers to voluntarily restrict their consumption of water. Cooperation was immediate but short-lived and on July 14th with consumption at 24.9 MGD the company, under authority of the Pennsylvania Public Utility Commission, announced mandatory controls on the use of water hoses for any purpose. This restriction applied to all customers. However, commercial car washing was permitted, as was the watering of lawns, gardens and the private washing of cars without the use of hoses. The results were again immediate and, with the exception of two days, total consumption fell below 20.0 MGD. Nevertheless, on July 22nd the company announced further restrictions on all car washing (private and commercial), the use of water-cooled air conditioners, filling of swimming pools, and serving water in restaurants. The company's July 14th and 22nd announcements on restrictions, as published in the two local newspapers, appear in Figure 5-2. The July 22nd restrictions, however, had relatively little impact on total system demands - mainly because the water to be saved was minimal compared with that to be saved as a result of the July 14th limitations.

Frequently during the water shortage period the company advertised the following suggested ways of conserving water in the home:

1. Use only the smallest amount of water needed for tub baths,
2. Take quick showers,
3. Do not let water run for hand washing,
4. Use a cup or glass of water when brushing teeth,
5. Wash only full washer loads,
6. Wash dishes only once a day,
7. Flush toilets less frequently,
8. Check plumbing fixtures for leaks, and
9. Serve drinking water only when requested.

By the end of July most of the water company's customers were well aware of the seriousness of the situation with the result that total system demands were limited, on most days, to a range of 12 to 18 MGD.

During July and August there were many stories in the two York daily newspapers on important developments in the drought, such as continuing lack of rainfall, drawdowns of the reservoir, requests for voluntary controls, ordering of mandatory controls and the hauling of water by tank truck. Stories also appeared on conservation measures taken by residential and commercial customers and on meetings of the industrial committees described below. One of the dailys, it should be noted, was critical of the water company for not having its second reservoir (which was under construction) in operation at the beginning of the drought, a situation which would certainly have precluded the difficulties in which the area found itself.

On August 17th, when there had been practically no flow in Codorus Creek at the pumping station for the past three weeks and the reservoir had been drawn down by 10-1/2 feet (approximately 50% of capacity), the company made arrangements to obtain water from two quarries in the area. About 70 MG were obtained from this source. In addition, the company began trucking water from the Susquehanna River as well as from other streams and quarries to put into its system. Such trucking, finally involving a fleet of over 60 vehicles working on an around-the-clock basis, was hauling over one MGD by August 23rd and then increasing to 4.2 MGD on September 10th. This approximate level of supplemental supply was maintained until September 14th, the day the rains came, and for all practical purposes, ended the drought. By this time, 67.3 MG had been hauled by truck for the company's system. As might be expected, and as will be explained in other sections of this report, the transportation involved in these emergency supply operations was an extremely expensive undertaking.

Shortly after the mandatory controls were ordered by the water company, most of the company's industrial customers became concerned, although such restrictions with the exception of use of hoses and water-cooled air conditioning did not apply to manufacturing activities. Nevertheless, a few companies attempted to protect their operations by digging wells (very little water was obtained this way and some wells were dry) and by trucking water. Most companies, however, tried various conservation measures such as water re-circulation, repair of leaking pipes and faucets and appeals to employees to conserve water wherever possible.

MANDATORY CONTROLS

Placed Into Effect

by

The York Water Company

On July 14th, 16th and 18th, the following announcement was placed in the York Daily Record and the York Dispatch by The York Water Company.

USE OF HOSE PROHIBITED

For Any Purpose

For Residential, Industrial and Commercial Customers

Commercial Car Washing Permitted

"Restrictions imposed under Rule 38 of our Rules and Regulations on file with the Pennsylvania Public Utility Commission. Penalty for failure to comply with these restrictions is covered by Rule 41 - which reads in part -

Discontinuance of Service

Service under any application may be discontinued after due notice for any of the following reasons:

(d) for willful waste of water
(j) for violation of any rule of the company"

On July 22nd The York Water Company announced the "further restrictions" in both of the York newspapers on:

"(1) car washing,

(2) water cooled air conditioning limited to 8 hours per day except for preservation of food, where medically required, and for systems using recirculated water.

(3) swimming pools, except for those equipped with filtering systems. Refilling of pools prohibited.

(4) restaurants to serve water only when requested."

FIGURE 5-2
MANDATORY CONTROLS

On August 22nd the Executive Committee of the Manufacturers' Association of York, Pennsylvania held a meeting with officials of The York Water Company to extend industry's assistance to the company. A larger follow-up meeting on August 29th included the above parties and the officials and representatives of 30 of the largest users of water supplied by the company. The water company reported on operations of the fleet of tank trucks that were by then hauling over one MGD for use in the company's system. After discussing several steps to save water in industrial operations, a few suggestions were made on the possible use of other water sources, such as:

1. The West Branch of the Codorus Creek (although the water would have to be chemically treated to make it potable),
2. The Susquehanna River, by laying a 16" to 20" pipeline with adequate pumping equipment up Codorus Creek - a distance of approximately 16 miles,
3. Use of two existing 8" oil lines to pump water from the Susquehanna, and
4. Use of railroad trains of 30 to 80 cars each to bring water from the Susquehanna.

At the August 29th meeting a special Manufacturers' Association Water Committee composed of engineers from the major water using companies was appointed to explore the water problem and determine how the committee might be of assistance to The York Water Company and to industry. This committee held an exploratory meeting on August 30th and discussed each of the supplementary supply possibilities. Later the same day the new committee met with officials of The York Water Company. This meeting, also, resulted in a general discussion of existing problems and how they were being explored. On September 2nd the special committee recommended the following actions:

1. immediate steps to assure continuation of trucks for hauling water,
2. immediate steps for procurement of water by railroad tank cars,

3. immediate steps to contract for purchasing and laying 20" pipeline from the confluence of the Susquehanna and Fishing Creek to the company's pumping station,

4. continue efforts to determine feasibility of West Branch source usage, and

5. daily unified reporting on the situation.

The association's Board of Directors with the knowledge of the General Manager of the water company and a representative of the U. S. Office of Emergency Planning asked that the water company's executive committee meet within 24 hours to expedite the above recommendations. As of September 2nd the company's reservoir had been drawn down approximately 65% below full capacity.

The record shows that the water company continued to haul approximately four MGD until the drought was broken by heavy rains on September 14th. Because of numerous complications, mainly in connection with the unavailability of tank cars, the recommendation of supplementing supplies by rail was abandoned. A portable chemical treatment plant was stationed on the West Branch of the Codorus Creek at considerable expense to the water company, but the drought was terminated before it became necessary to put it into service.

The following statement taken from an engineering report on the water company's 1966 operations provides a brief description of developments on the proposed pipeline from the Susquehanna River to the city of York:

> "Two hearings were held before the Pennsylvania Public Utility Commission in an effort by that body to determine the extent of the drouth as it affected the area and population served by the Company and to seek means for alleviating the condition. The hearings resulted in an order being issued which instructed the Water Company to direct its engineers to prepare plans and specifications for the construction of a temporary pipe line and pumping facilities to deliver Susquehanna River water to The York Water Company facility in an amount which would satisfy the necessary demands.

"When the reservoir began to fill, the status of the water supply was improving and consequently the order to construct a pipeline to the river was held in abeyance by the Commission pending a recurrence of the drought conditions. This pipeline would have involved an expenditure of nearly $1,500,000 and the line would have been laid in the limits of Codorus Creek to obviate the necessity of procuring right-of-way. After the drought was over it would have been necessary to remove the pipeline from the creek bed. The line contemplated was never considered to be of a permanent nature and as such, constituted a very large expense item in operating cost of the Company. Fortunately, the need for the line did not materialize and the line was not built."

ENGINEERING FEATURES

The company obtains its supply of water from the East Branch and South Branch of Codorus Creek, which drains an area of approximately 117 square miles. On the East Branch are the company's two reservoirs. The first, known as Lake Williams, had a capacity of 1,150 million gallons at the time of the 1966 water shortage. In the late 1950's it became apparent that a second reservoir would be required to maintain adequate water reserves for the area. This reservoir (with a total capacity of 1,600 million gallons) was also designed for the East Branch basin immediately upstream from Lake Williams. Because of delays in obtaining the required approvals from various agencies of the Commonwealth of Pennsylvania and in finalizing designs, construction was not begun until January of 1966, about one year behind schedule. The new reservoir, recently named Lake Redman, was filled by May, 1967. If it had been filled a year earlier as planned, the drought, although serious, would not have resulted in the severe water shortage that actually occurred.

The company's pumping station at Brillhart is about a mile downstream from the confluence of the East Branch and the South Branch of Codorus Creek. It has a capacity of 71 MGD, more than double the company's system requirements.

This water is pumped directly to the company's filter plant, a distance of approximately two miles. At the filter plant are two mixing basins. From there the water is conducted to two settling basins and then to the filters. The two filtered water reservoirs have a capacity of 34 MG.

In 1966 the company's distribution system consisted of approximately 340 miles of cast iron mains varying in size from 3" to 25" and 30,000 service lines. Daily consumption generally varies from a low of 10 MG to a high of 25.5 MG. As a part of the distribution system the company has eight pumping stations and seven steel standpipes ranging in volume from .3 MG to 2.0 MG, having a total storage capacity of about 8.5 MG. Largely because of the different elevations in York the company has in effect two delivery systems: a "gravity" system mainly for customers at the lower elevations, especially those in the downtown area, and a "repumping" system for customers at relatively high elevations in the peripheral and suburban areas. About two-thirds of the company's 30,000 residential customers and one-fourth of its 2,000 commercial customers are on flat price rates: all of them are in the gravity system. The metered customers (residential, commercial, industrial and municipal) are on either gravity or repump rates. In the repumped areas the customers are charged more for the water to cover the additional pumping costs. In 1966, residential consumption accounted for approximately 57% of the total while commercial and industrial consumption amounted to 43%. Total consumption, including leaks and unaccounted for losses, in the company's entire system for that year was 6,021 MG.

DETERMINATION OF LOSSES

A determination of losses associated with each sector was made for the 1966 conditions. The viewpoint was from each sector; losses could be to other sectors within the regional boundary or to other points outside the boundary. Losses outside the boundary are regional losses and a methodology for their determination is presented in Chapter 6.

The only feasible way to obtain reliable data on losses suffered by various sectors of the York community because of the 1966 drought was to contact personally those persons most directly involved. In most cases this was done by formulating lists of questions to be asked in personal interviews. This was the procedure followed in talking with the water works managers and industrial managers or engineers not only in York, Pennsylvania, but also in Harrisonburg, Virginia, and West Chester, Pennsylvania. Less formalized questions were put to the commercial sector and most of those contacted appeared to have weathered the drought with little difficulty. For the domestic sector no interviews were held because of the time consuming effort that would have been involved, but a questionnaire was sent out with the water bills.

Residential Sector

The questionnaire sent to approximately 7900 flat rate residential customers (about 40% of the total number) and 9200 of the approximately 10,000 metered residential customers appears in Figure 5-3. It should be noted that the same questionnaire was sent to both groups. The York Water Company sent out questionnaires in one of its monthly billings and asked customers to return it with their remittance. Approximately 1,000 or 13% of the flat rate sample returned their questionnaires. From the sample of metered customers, about 2,000 questionnaires were received representing a response of 22%. Mainly because the company's metered customers have for some time complained about the flat rates applying to others, especially during the summer months when flat rate customers were usually consuming unlimited supplies of water at no extra charge, it is not surprising that response of the metered customers was twice that of the flat rate customers.

The following information was obtained from the questionnaires returned by <u>flat rate</u> residential customers:

1. 93.5% of them lived in York during the summer and autumn of 1966;
2. 98.7% of those that lived in York during that time were aware of the drought;

QUESTIONNAIRE TO RESIDENTIAL WATER CUSTOMERS

Although The York Water Company has more than adequate capacities for the foreseeable future, we shall appreciate your answering the following questions on the 1966 drought. This information will be used for state and regional water resource planning. Replies will be strictly anonymous inasmuch as no names or addresses are being requested. Please answer the questions to the best of your knowledge and return this questionnaire with your remittance.

- Did you live in the York area during the summer and autumn of 1966? (If "no," please ignore the following questions)
  - YES ____ (1)
  - NO ____ (2)

- Were you aware of the drought in 1966? (If "no" please ignore the following questions)
  - YES ____ (3)
  - NO ____ (4)

- What degree of inconvenience did you experience during the drought? (Please check only one)
  - MAJOR ____ (5)
  - MINOR ____ (6)
  - NONE ____ (7)

- What financial loss, if any, did you suffer from the drought? (Please check only one)
  - NEGLIGIBLE ____ (8)
  - UNDER $50 ____ (9)
  - $50-$100 ____ (10)
  - $100-$500 ____ (11)
  - $500-$1000 ____ (12)
  - OVER $1000 ____ (13)

- If you suffered a loss, was it due to damage to:
  - LAWNS & SHRUBS ____ (14)
  - OTHERS ____ (15)

- If "others," please explain (briefly) on lines below.

  ____

  ____

  ______________________________.

- In the 1966 drought, which of the following uses did you restrict, if any, to save water? (Please indicate only your restricted uses and in the order that you took them—1, 2, 3, etc.) For example, if you stopped sprinkling the lawn first, put a "1" in the blank next to lawn sprinkling. Then a "2' in the next restricted use, etc. You need not rank all 6 water use restrictions.
  - CAR WASHING ____ (16)
  - DISHWASHING ____ (17)
  - LAUNDRY ____ (18)
  - LAWN SPRINKLING ____ (19)
  - TOILETS ____ (20)
  - TUB OR SHOWER ____ (21)

FIGURE 5-3

SAMPLE OF RESIDENTIAL QUESTIONNAIRE

3. 73.3% of them considered the inconvenience experienced during the drought to be minor; 19.1% experienced no inconvenience; and only 7.7% considered such inconvenience to be major;

4. 80.9% of the respondents indicated they had suffered only a negligible financial loss during the drought; 10.1% indicated a loss of under $50; 5.4% a loss between $50 and $100; 2.2% a loss between $100 and $500; 1.3% a loss between $500 and $1000; and 0.3% a loss of over $1000. (See Table 5-3); the total flat rate residential losses are estimated to be $319,180;

5. 34.0% of those suffering a loss indicated it was due to damage to lawns and shrubs; only 2.2% indicated "other" losses - mainly to flower and vegetable gardens; and 63.8% did not answer the question; and

6. Respondents' voluntary restrictions on saving water during the drought, in order of priority as indicated by them, were the following:

    a. lawn sprinkling;

    b. car washing;

    c. tub or shower;

    d. laundry

    e. dishwashing, and

    f. toilets.

The following information was obtained from the questionnaires returned by metered residential customers:

1. 83.2% of them lived in York during the summer and autumn of 1966;

2. 99.3% of those that lived in York during that time were aware of the drought;

3. 77.8% of them considered the inconvenience experienced during the drought to be minor; 13.4% experienced no inconvenience; and only 8.8% considered such inconvenience to be major;

4. 74.6% of the respondents indicated they had suffered only a negligible financial loss; 12.7% indicated a loss of under $50; 8.2% a loss between $50 and $100; 4.1% a loss between $100 and $500; 0.25% a loss between $500 and $1000; and 0.15% a loss in excess of $1000 (See Table 5-3); the total metered customers' losses are estimated to be $100,740;
5. 40.3% of those suffering a loss indicated it was due to damage to lawns and shrubs; only 1.8% indicated "other" losses mainly to flower and vegetable gardens; and 58.0% did not answer the question; and
6. respondents' voluntary restrictions on saving water during the drought, in order of priority as indicated by them, were the following:
   a. lawn sprinkling,
   b. car washing,
   c. tub or shower,
   d. laundry,
   e. toilets, and
   f. dishwashing.

A comparison of the economic response of flat rate and metered customers is shown in Figure 5-4. Apparently the metered customers felt a larger loss. A rationalization of this may be that flat rate customers, who enjoy lower costs and higher usage, had more latitude for water conservation.

In addition to the responses summarized above from residential customers, a number of gratuitous comments were obtained. Most were in the form of complaints mainly on the inconvenience involved in not being able to water lawns and gardens by hose (although water carried in a bucket for such purpose was allowed); the dust resulting from the drought, especially from the fleet of trucks used for hauling water; and on the costs involved in digging wells. There were also a number of complaints about water quality - mainly on color and taste. A number of residents, also, were concerned about possible health hazards, and as a result, a fairly large amount of bottled water was sold during the drought.

Also, there were many complaints from metered customers, which the water company had heard on numerous other occasions, that they were being discriminated against because flat rate customers had unlimited use of water and there was no way of checking on their consumption short of daily visual inspection. Finally, there were the expected complaints that some customers, metered as well as flat rate, were not abiding by the restrictions by indulging in surreptitious lawn and garden watering by hose at night. To counteract such activities, the water company organized several inspection teams and a few customers were warned. When the drought was over, however, the general manager of the water company stated that in his opinion at least 95% of the customers had been cooperative.

In determining the monetary losses to the residential customers of The York Water Company, the data obtained from answers to question (4) of the questionnaire shown in Figure 5-3 were used. To compute total domestic losses, the low dollar figure for each range of loss was used (e.g., for the range $50 to $100, the $50 figure was used, although for the range under $50, the figure $10 was used), and each of these was multiplied by the total number of customers estimated to be in each category, based on the percentage distribution as determined from responses to the questionnaire. As shown in Table 5-3, such losses for all residential customers, flat rate as well as metered, during the 1966 drought in York amounted to $420,000, or approximately $14 per service connection.

Using the techniques presented in the next chapter, the consumer surplus loss for lawn and garden sprinkling amounted to approximately $125,000 in the 1966 drought. This represents the difference in the demand for water and the available supply.

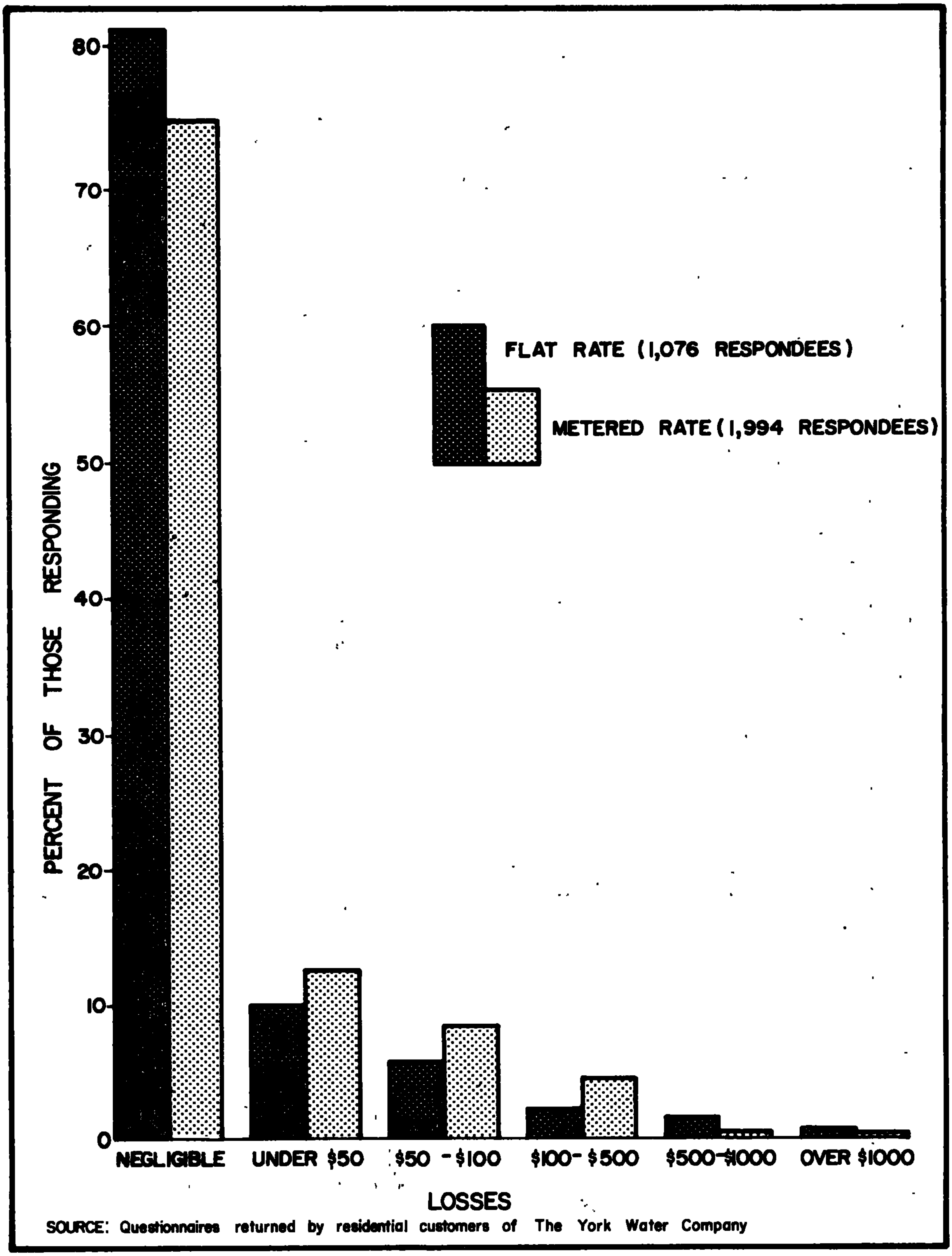


FIGURE 5-4

PERCENT DISTRIBUTION OF LOSSES TO RESIDENTIAL CUSTOMERS

TABLE 5-3 Losses Suffered By Residential Customers (Flat Rate and Metered) in 1966 Drought

Loss Categories (A)	Respondees (B)	Percent Distribution (C)	Total No. of Customers (D)	Estimated Distribution of all Customers Col (C) x Total of (D) (E)	Estimated Losses Per Loss Category (F)	Estimated Total Losses Col (E)x(F) (G)	Cumulative Losses (H)
Flat Rate Customers							
Negligible	870	80.9%		16,965	$ 0	$ 0	$ 0
Under $50	109	10.1		2,118	10	21,180	21,180
$50 to $100	58	5.4		1,132	50	56,600	77,780
$100 to $500	22	2.0		419	100	41,900	119,680
$500 to $1000	14	1.3		273	500	136,500	256,180
Over $1000	3	0.3		63	1,000	63,000	319,180
Sub-Totals	1076	100.0%	20,970	20,970	-	$319,180	-
Metered Customers							
Negligible	1488	74.6%		6,403	$ 0	$ 0	$ 0
Under $50	253	12.7		1,089	10	10,890	10,890
$50 to $100	164	8.2		703	50	35,150	46,040
$100 to $500	82	4.1		352	100	35,200	81,240
$500 to $1000	5	.25		21	500	10,500	91,740
Over $1000	2	.15		9	1,000	9,000	100,740
Sub-Totals	1994	100.0%	8,577	8,577		100,740	
Grand Totals	3070		29,547			$419,920	

Total Losses - $419,920 ÷ 29,547 = $14.20 per Residential Customer

Source: Questionnaires Returned by Residential Customers of The York Water Company.

Industrial Sector

In October 1966 after the drought was over and the water company's reservoir was refilling, the Manufacturers' Association of York conducted a mail survey of its membership to determine estimated shortage costs. Such costs were subdivided among the following:

1. drilling of wells,
2. labor and materials,
3. engineering services,
4. shutdown of testing facilities using water,
5. water treatment, and
6. miscellaneous.

Costs for each of these categories are given in Table 5-4. As shown, total costs for coping with the drought amount to $104,000 for externally owned companies and $35,000 for those locally owned. The total water consumption for all of these companies accounted for 80% of all industrial consumption, and 25% of total consumption of The York Water Company in 1966.

In visits with industrial plant personnel familiar with their company's activities during the 1966 drought, a list of questions shown in Figure 5-5 was generally used to start the interview. In most cases, plant personnel were very cooperative in recounting the many different problems encountered during the drought. A varied number of emergency measures were taken to cope with such problems. Among the most usual ones were:

1. a general request to all employees to conserve water throughout the plant;
2. the digging of wells on plant property (most of which produced little or no water);
3. tapping of nearby creeks, ponds, and quarries;
4. hauling in water by tank truck;

TABLE 5-4 Expenses For Emergency Services and Supplies Incurred By Large Water Consuming Firms in the York Area During 1966 Water Shortage Period

Services and Supplies	4 Firms Locally Owned	21 Firms Externally Owned	Total of 25 Firms
Well Drilling	$ 9,000	$ 21,772	$ 30,772
Processing Changes to Conserve Water	13,000	38,833	51,833
Engineering Services	5,000	18,678	23,678
Losses Resulting from Stopping of Testing Facilities Requiring Water	-	14,500	14,500
Supplementary Water Treatment	1,000	6,051	7,051
Other Expenses	7,500	4,555	12,055
TOTALS	$35,500	$104,389	$139,889

Source: Survey of the Manufacturers' Association of York, Pennsylvania

FIGURE 5-5 QUESTIONS ASKED OF INDUSTRIAL FIRMS

I <u>Initial</u>

Name of Company ______________________

Address ______________________

Company in Business

In This City Since ______________________

At This Plant Site Since ______________________

Main Product Lines ______________________

Person Interviewed ______________________

Position of Interviewee ______________________

Telephone Number ______________________

Date of Interview ______________________

II <u>Company's Intake of Water by Source</u> (in millions of gallons).

	1953	1959	1963	1968
From Public Water System				
From Company's Water System				
Surface				
Ground				
Tidewater				
TOTAL				

III <u>Company's Chronology of Actions Taken During Water Shortage Period</u>.

____

____

____

Please show:

1. What actions - digging wells, trucking in water, installation of recirculating equipment, etc.;
2. When;
3. Whether such actions were voluntary or mandatory;
4. About what percentage of intake water was <u>saved</u> in so doing; and
5. Total cost of such actions.

FIGURE 5-5 (continued)

IV Projected Operations During Future Drought Periods.

What actions would your company be likely to take in the future if your supplies of water are reduced by:

10%	________________	40%	________________
20%	________________	50%	________________
30%	________________	100%	________________

NOTE: If drastic change between 50% and 100%, locate at what per cent such change occurs.

5. installation of water re-circulation facilities and equipment; and
6. postponing strictly non-productive operations such as research, development, and testing operations where significant amounts of water were used.

Commercial Sector

Interviews were held with several retail and service establishments in the York area on the impacts of the 1966 drought. With the exception of commercial car washing establishments and nurseries, no problems of any real significance were encountered. One of the car washing establishments dug a well (since capped) and the others brought in water by truck to provide the required supplies. The only substantial loss was a nursery's purchase of $30,000 worth of stock that was completely ruined because of the ban on sprinkling.

Municipal Sector

In this report the municipal sector includes not only such public facilities as the fire department, parks, playgrounds, swimming pools, etc., but The York Water Company as well. In most communities the water department is municipally owned and operated and, therefore, in the analytical procedure losses encountered by the water works whether publicly or privately owned are considered to be losses within the municipal sector.

In the summer of 1966, The York Water Company began recording its extraordinary expenses resulting from the drought, with the first entry made on July 27th for water obtained from a local quarry. Such accounts were subclassified as to quarries, trucking, railroad, pipeline, portable pumping equipment for the West Branch of the Codorus and others. Total costs to the company for these emergency payments amounted to $498,688 to local firms, and $41,235 to externally-owned enterprises for a combined total of $539,962 as shown in Table 5-5. It is important to note that the largest expenditure by far was the $390,547 for the 65.8 MG of water obtained by truck resulting in a unit cost of almost $6 per thousand gallons. The 69.8 gallons of quarry water cost about $42,000, or about 60¢ per thousand gallons. During the previous year, by contrast, the company's figures show a total cost of water delivered to its mains of 19.35 cents per thousand gallons. The high cost of the emergency water was borne by the water company in order to maintain the amount of good quality water needed to meet even the reduced demands. The pumping equipment installed at the West Branch of the Codorus at a cost of $47,000 was never placed into service and was finally dismantled. The water pumped from here would have required chemical treatment in addition to that normally required to overcome poor water quality of the West Branch.

In addition to the above mentioned emergency expenditures, the water company also suffered certain losses of revenue due largely to the voluntary and mandatory water use restrictions. Such losses are based on the difference between the average dollar value of 1966 water bills for each class of customer and the average of similar bills paid in 1965 and 1967. The difference in each class is multiplied by the corresponding number of customers to obtain the total loss. Such revenue losses to the water company amounted to $4,975 for residential customers and $24,881 for industrial and commercial for a total of $29,856. These lost revenues, however, amounted to only 1.28% of the company's total revenues for 1966. The total lost to the water company is the sum of the cost of emergency supplies and the lost revenue. This amounts to approximately $570,000.

Apart from the water company, the municipal sector suffered no significant losses that could be measured in dollar terms. It was learned from city officials that some parks and other recreational area and public building lawns turned brown and shrubbery suffered from lack of water during the drought, but these were only negligible actual losses.

TABLE 5-5 Expenses For Emergency Water Incurred by The York Water Company 1966

	Paid To Firms		
	Locally Owned	Externally Owned	Total
Quarries	$ 40,475	$ 1,427	$ 41,902
Trucking	386,327	4,220	390,547
Railroad	1,703	5,388	7,091
Pipeline	600	7,504	8,104
West Branch	45,955	1,507	47,462
Other	23,628	21,189	44,817
TOTALS	$498,688	$41,235	$539,923

Source: Records of The York Water Company

The York Fire Department, however, was concerned about the availability of sufficient supplies of water in the event of one or more large-scale fires during the drought. The department initiated an action program which included:

1. asking citizens to conserve water because it might be needed to fight fires,
2. keeping a 3,000 gallon tank truck filled with water at all times,
3. making arrangements with a commercial tank truck firm to have other trucks filled with water and be in continual states of readiness,
4. reaching agreements with about 70 fire departments (most of them volunteer) in York County to have a number of tank trucks filled with water and ready to go to each other's assistance in the event of large fires, and
5. obtaining several tons of sand and hundreds of jute bags to dam the Codorus Creek in a hurry to obtain water in the event of a large fire.

Finally, the city health department made more frequent bacterial tests at several points in the city, especially at the hospitals.

HARRISONBURG, VIRGINIA

Harrisonburg, the county seat of Rockingham County, is in the heart of the Shenandoah Valley in the western part of Virginia near the intersections of federal highways 81 and 33. The city in 1966 had a population of approximately 14,000.

The water department is a municipally-owned and operated enterprise with its main source of supply at Rawley Springs (not really a spring, but actually a mountain stream known as Dry River). For storage, the city has two reservoirs with a combined capacity of 21 million gallons and three supplemental tanks with a combined capacity of nearly 700,000 gallons.

In 1966 the total system demand, including losses and consumption of non-metered customers (only 1% of the customers are in that category) amounted to approximately 2 MGD. At that time there were roughly 4,000 residential, 500 commercial and six industrial customers. Another large customer was a state school, Madison College. The industrial customers and the college accounted for about 20% of the total system demands.

The Harrisonburg water manager's definition of a water shortage was simply when rainfall "falls short," and it was abnormally short in the spring months of 1966. Consequently, because of low flows at Rawley Springs, the city began pumping from its emergency source of supply, Silver Lake. This action brought many complaints from the local citizens. The water from Rawley Springs is of excellent quality and is normally only treated by chlorination, but the water from Silver Lake is very hard and there were no facilities for a softening process. Many people complained that they had difficulties washing their clothes or bathing due to the hardness of the water.

By July 1966 the water manager and others in the city government became concerned and by mid-August the situation was obviously acute. During July the city had been getting most of its water supplies from Silver Lake at a rate of about 1.5 MGD - a body of water which had a normal overflow of about 4.5 MGD. By early September the Silver Lake overflow was down to 0.5 MGD, close to the minimum overflow level required by the state government and flows at Rawley Springs also continued at abnormally low levels. By this time many wells in the area had gone dry.

Consequently, in early September the city government requested customers to voluntarily restrict their consumption of water for use on lawns, shrubs, gardens also motor vehicles and driveways. Industry was asked to limit its consumption. Cooperation was immediate and widespread, but the drought continued and in the first week of October the city government ordered mandatory controls for each of the previously designated voluntary restrictions. Compliance was very good, but reservoir levels were getting lower. Concurrently, the city government and others in the area were concerned about the health hazards that might ensue, even though all available sources of water were being filtered and chemically treated.

As an additional conservation measure, it was suggested to reduce pressures in the mains. The water manager, however, took a firm stand against such a step, pointing out that at several points in the city sewer lines were laid close to water mains, and sewage leaks might possibly infiltrate low pressure water lines resulting in a considerable health hazard.

Despite the serious shortage of water no industrial production operations had to be cut back. Had such a move been necessary, city officials planned to cut back industry on a non-discriminating basis, such as a certain given percentage of production. The last customers to be seriously curtailed would have been residential customers.

The long hoped for rains came the end of October and they were above normal during November. Flows from Rawley Springs were also improving, but some water was still being taken from Silver Lake. By the end of November the water shortage period was practically over.

The financial losses resulting from the 1966 drought in Harrisonburg were minimal. The emergency pumping of water at Silver Lake during the summer cost the city about $8,000. Some lawns and gardens suffered temporary losses, but most were restored at relatively low costs. No industrial nor commercial operations were reduced because of the water shortage and consequently no payrolls were lost. Even swimming pools were kept in operation by continuous re-circulation and carefully controlled chemical treatment.

Mainly because of the drought and increasing demand for water, however, the city government decided to build a pumping station on a new source of supply, the North River. The North River, itself of poor quality in comparison to Rawley Springs, is of better quality than the local ground water which has high iron content. To process North River water, the city built a 5 MGD filtration plant at a cost of 1.1 million dollars. Public reaction to the entire situation was negative; the idea of consuming the wastes of people living upstream on the North River provoked adverse comment. State health department and city officials had to make public assurances concerning safety of the treated water for drinking purposes.

Subsequently, water rates were raised about 10% to help defray part of the costs of the facility's construction and its operation. The city was also considering the construction of an additional dam at Rawley Springs. Furthermore, several of the industrial firms in the area made changes in their water using procedures and equipment attempting to re-circulate and institute other water conservation measures. According to the city water manager, it appears that such measures were at least moderately successful.

WEST CHESTER, PENNSYLVANIA

The Borough of West Chester, the county seat of Chester County, is in the southeastern part of Pennsylvania, roughly 15 miles north of Wilmington, Delaware, and 20 miles west of Philadelphia. In 1966 the borough had a population of approximately 18,000, most of whom were served by the borough's water department. Another 2,000 in the adjoining West Goshen Township were also served by the department.

The borough's water department is a municipally owned and operated enterprise with its main source of supply being the East Branch of Chester Creek and several wells in the area. The wells are generally used only during the summer months to help fill the raw water reservoir for use during the remainder of the year which is usually the period of high demand, primarily because the largest user of water in the area is the West Chester State College.

The creek has a dependable supply of 3.6 MGD and there is another 1.0 MGD available from the wells. The water department's raw water reservoir has a capacity of 2.25 MG and a 3.0 MG finished water reservoir with storage tanks having a combined capacity of 1.0 MG. The department also has a pumping station and a treatment plant.

The entire system is almost entirely dependent on the availability of electric power because water has to be pumped from the wells and also from the treatment plant to the finished water reservoir and tanks. If the power goes off (the department does not have emergency pumping or generating equipment) the only water that will be available is the 1.0 MG in the storage tanks. With system demands of approximately 5 MG on a normal day, the storage tank water is usually adequate for less than five hours.

In short, the borough has been living with a chronic water shortage situation. Adequate surface water appears to be available, but the borough is short on reservoir and other storage capacity and on emergency pumping equipment.

This very difficult supply situation, according to the water manager, is due in large part to the reluctance of the borough's council to commit itself to the financing of a $5 million water plant expansion that a consulting engineering firm recommended. Such expansion would include construction of about three miles of line to obtain approximately 3.3 MGD from Brandywine Creek, although such diversion would require approval of the Delaware River Basin Commission which could be reluctant to grant it.

Because of short water supply in West Chester, fire insurance rates in the area are quite high. Furthermore, several of the larger industrial firms have found it necessary to dig their own wells. These situations have apparently been important factors in the decision of several large industrial firms interested in locating in West Chester to acquire facilities elsewhere.

The water department in 1966 served about 4,000 residential, 300 commercial and 20 industrial customers. Its largest user of water is the West Chester State College. The entire system is metered.

In June 1966 it became apparent that a severe water shortage situation was developing. Precipitation was considerably below normal and despite the fact that the department's wells were being pumped heavily, the reservoir was being drawn down much faster than in many previous summers. Consequently, additional wells were dug along the East Branch of Chester Creek and the well water was pumped into the creek through pipe obtained from the U. S. Office of Civil Defense.

In July voluntary restrictions were requested on the use of hose for lawn watering and car washing by all customers, but no mandatory controls were ordered; primarily because the West Chester State College was not in session. The drought continued through August and practically all customers cooperated in their conservation of water. The rains finally came in mid-September and the drought was over, but the reservoir was low and there was still the problem of supplying the demands of the college, just beginning its fall term. The water department advised the college of the situation and notices requesting student cooperation were posted in all appropriate places. With a fairly normal display of exhuberance, the students reacted in a somewhat different fashion. They turned on as many faucets, showers, and toilets as possible in expectation of an extended vacation should water supplies be exhausted. They would undoubtedly have achieved their goal had not the rains continued.

6. LOSS FUNCTIONS

The objective of this section is to describe how the regional economic responses associated with a water supply shortage are reduced to regional loss functions for use in the simulation model.

The York Water Company's service district is considered as the boundary for evaluating the economic mass balance. Dollar flows or leakage across this boundary (to the outside) associated with shortage, are estimated in this chapter. Economic leakage derives from four sectors located within the boundary: municipal, domestic, commercial and local industrial. This section is organized around and concerns major sources[1] of leakage and focuses upon the five types of leakage:

1. Cost of imported water to the area (municipal sector),
2. Loss of both production payroll and water company revenue from externally owned industry (municipal and domestic sectors),
3. The profits and fixed costs lost by locally owned industry (local industrial sector),
4. Lost consumer surplus (domestic sector), and
5. Non-replenished stock losses suffered by all sectors (but mostly the commercial sector).

Note that leakages across sector boundaries, both inside and outside the regional boundary, are discussed in Chapter 5. These losses were associated with 1966 conditions and were examined to determine the major sources of leakage.

In order to evaluate the magnitude of these various losses under different water shortage conditions, it is necessary to develop techniques

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[1] The loss components associated with secondary (or multiplier) economic effects are not assumed to be major factors in this study. Data for measuring such components were not obtained.

to construct functions which describe loss information for each of the five sources. Given varying levels of shortage, the mathematical relationships which depict the associated losses for each source are called loss functions. For example, Figure 6-1 shows the regional industrial production related losses associated with water restrictions. The procedures used to develop this figure and the other loss data are presented in this chapter.

Once again it is emphasized that the methodology concerns a regional boundary. With a minor shift in emphasis the boundary could be contracted to inscribe individual sectors. For example, a boundary could be drawn around the domestic sector and the analysis could give facilities and demand schedules which vary from the regional viewpoint, as defined herein. The data and information presented in Chapter 5 support such an analysis, and other investigators may wish to define other boundaries.

IMPORTED WATER

The first source of loss is the cost associated with the water imported to the area to relieve the shortage conditions. This cost can be incurred by the domestic, industrial or commercial sector; but is more than likely borne by the municipal sector. In the case of York, the only significant amount of importing was done by The York Water Company as the only major supplier in the district. The only part of the cost that is counted as a loss to the study area is the money that flows to outside recipients; any money spent by the water company for goods and services to suppliers inside the service area is not considered lost to the district. To develop a cost relationship for the water imported to the York area requires the use of the official records of The York Water Company. The water company has a complete accounting record of all costs associated with importing emergency supplies during the 1966 shortage period. An aggregation of these expenses is presented in Table 5-5.

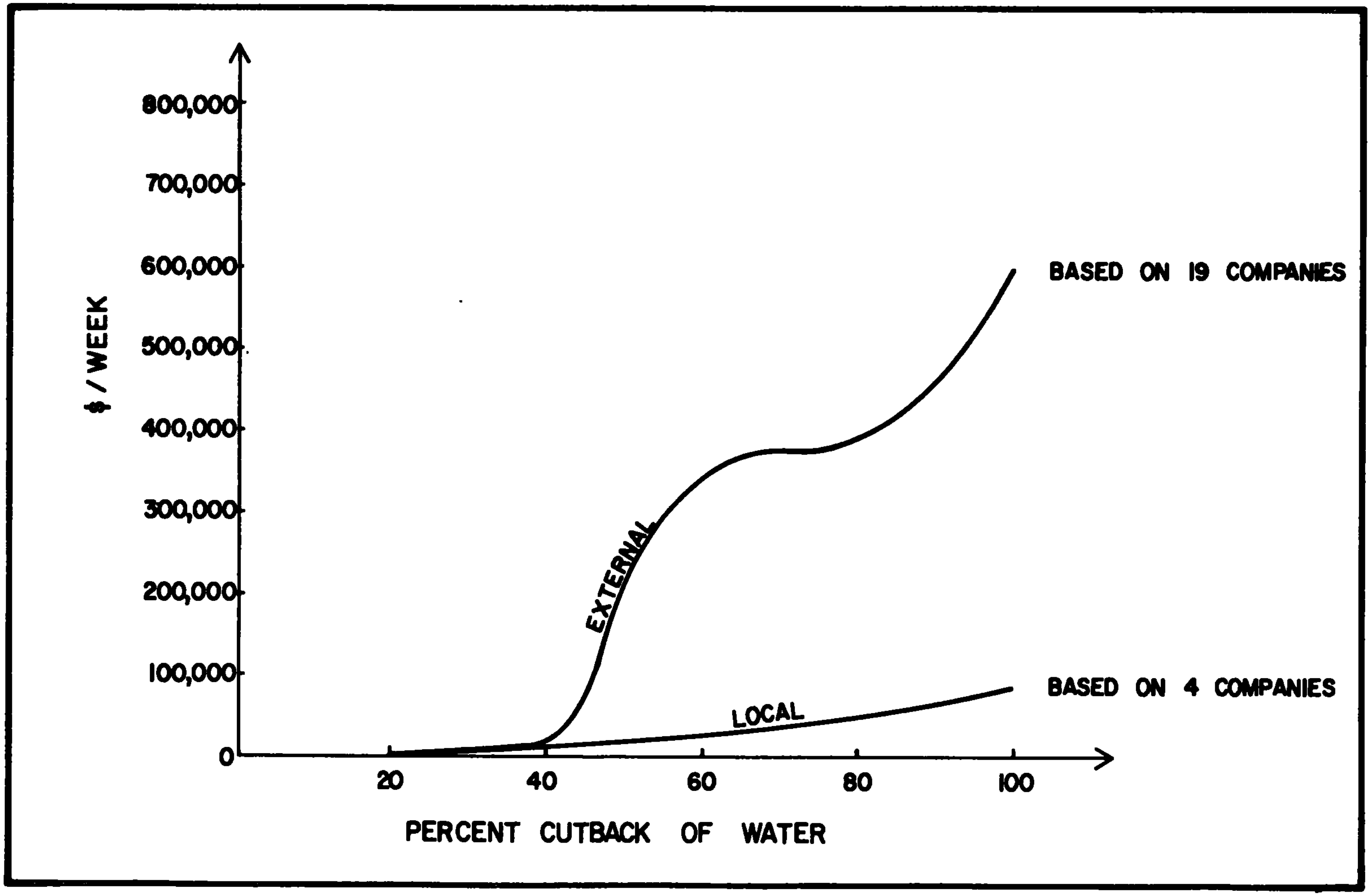

FIGURE 6-1
INDUSTRIAL LOSSES

There are basically two cost alternatives available to the supplier considering the importation of emergency supplies. One is a low capital cost but high operating expense procedure, while the other has a high capital cost with fairly low operating expenses.

In 1966, The York Water Company initially selected the first alternative. Water was trucked into the area from the Susquehanna River and also piped from abandoned quarries in the vicinity of York. Altogether, 137.1 million gallons of water were imported at a total cost of $539,962, of which $41,235 or 8.27% were paid to external sources. Of the 137.1 million gallons imported, 67.3 million gallons were trucked at a total cost of $390,547. The trucked water was put through the complete treatment process, thus representing an additional cost of $5.80/1000 gallons to the company. The trucking operation was capable of delivering an average of 2.5 million gallons per day to the York area. Water was pumped from the quarries at an average rate of 1.0 million gallons per day for seventy-six days, yielding a total of 69.8 million gallons. The water from the quarries was judged safe for human consumption and the water company simply chlorinated and pumped it directly into the distribution system. This resulted in some savings in treatment costs to the company; however, $41,902 were spent to get the quarry water, resulting in a unit cost after savings on treatment costs of $.58 per 1000 gallons. The remaining $107,513 of the total $539,962 lost by the water company were spent for evaluating alternative methods to supplement their supply. The simulation uses the unit costs derived from the 1966 experience for the two classes, trucked and quarry, of imported water to estimate the losses associated with other shortage conditions.

With the eventual worsening of the conditions in 1966 and no relief in sight, pressure was brought to bear on the water company to go to the second alternative, a high capital cost but lower operating cost procedure. This course of action involves the construction of a temporary pipeline to the Susquehanna River. The advantage of this alternative from the citizens' standpoint was a dependable supply of water. The estimated initial cost of the pipeline capable of delivering 8.5 million gallons per day, including the cost of two pumping stations, ten miles of pipe, and the labor, was $650,000. Fortunately the drought ended and this system was never installed. However, for the purpose of simulating more severe shortage conditions when the pipeline may be needed, this estimate is used to calculate the losses associated with the installation of a pipeline to import water. The transmission costs, including maintenance, of the imported Susquehanna water are calculated from the equation

$$C_T = 1.08 \left(\frac{1.66 \times 10^{-2} \, (L_1 S_1 + L_f S_f) P}{E} \right) , \qquad (6\text{-}1)$$

where,

C_T = transmission cost including maintenance ($/1000 gal/mile),

E = efficiency factor (fraction),

L_1, L_f = loading factors (fraction of total capacity),

P = cost of energy ($/kilowatt hour),

S_1 = slope of the pipe (ft/1000 ft), and

S_f = friction loss (ft/1000 ft).

An estimate of the friction losses is given by

$$S_f = Q^{1.85} \cdot 10^3 \;/\; (405 \times 10^{-6} \cdot C \cdot D^{2.63})^{1.85} . \qquad (6\text{-}2)$$

where,

C = Hazen-Williams coefficient,

D = pipe diameter (inches), and

Q = pipeflow (million gallons/day).

The Susquehanna water transmission line planned for York has a 20 inch pipe with a flow of 8.5 million gallons per day. Using fully loaded pipes ($L_1 = L_f = 1$) with a Hazen-Williams coefficient equal to 120 which implies a friction loss, S_f, of 6.7 feet/1000 feet, the pipeline slope (10 feet/1000 feet), a cost of energy (.01 $/kilowatt hour), and an efficiency of 92%, a transmission and maintenance cost of $32 per million gallons for the ten mile transmission is computed.

The following is a summary of the import costs used in the simulation for the different alternatives available to increase supply:

ALTERNATIVE	INITIAL COSTS	OPERATING COSTS
Quarry Water	-	$ .58/1000 gal.
Trucking Water	-	$5.80/1000 gal.
Susquehanna Pipeline	$650,000	$ .032/1000 gal.

EXTERNALLY OWNED INDUSTRY

The externally owned industrial loss[1] has two components, the loss of production payroll in the York area and the loss of water company revenue. The first component is computed by using the values shown in Table 6-1. This table presents the steps taken to determine the weekly production payroll of the 19 largest externally owned water sensitive industries in the York area. These industries are grouped under their appropriate SIC categories and estimate the payroll to be lost due to various production cut-backs. It should be understood that these steps are taken to assist in developing a methodology that could be used to determine loss functions for practically any urban-industrial area faced with a water shortage situation.

[1] The possibility exists that a plant manager, faced with a short term water restriction, could postpone production and maintain quotas later using overtime. This would cause a "time shift" in production and reduce losses. The 1966 data did not enable estimates of this effect to be made. In this report, the time shift is not considered, a fact which may impart an upward bias to the loss estimates.

TABLE 6-1(a). Estimated Number of Production Workers in 1966 for Externally Owned Large Water Using Companies in the York Area

Company Number (A)	Kind of Products (B)	SIC Class[1] (C)	Ave. No. of Total Employees (in 1966)[1] (D)	Percent of Production Employees to All Employees[2] (E)	Estimated No. of Production Workers (in 1966) Col (E) x Col (D) (F)
1	Refrigeration Machinery	3585	3,351	71%	2,379
2	Paperboard Mills	2631	259	84%	218
3	Ordnance & Accessories	1929	1,555	82%	1,275
4	Malleable Iron Foundries	3322	1,033	83%	857
5	Misc. Fabricated Wire Products	3481	426	80%	341
6	Asphalt Felts & Coatings	2952	205	86%	176
7	Construction Machinery	3531	1,329	75%	997
8	Nonferrous Wiredrawing (Plant 1)	3357	62	82%	51
9	Nonferrous Wiredrawing (Plant 2)	3357	137	82%	112
10	Welding Apparatus (Plant 1)	3623	592	62%	367

TABLE 6-1(a)-Continued

Company Number (A)	Kind of Products (B)	SIC Class[1] (C)	Ave. No. of Total Employees (in 1966)[1] (D)	Percent of Production Employees to All Employees[2] (E)	Estimated No. of Production Workers (in 1966) Col (E) x Col (D) (F)
11	Welding Apparatus (Plant 2)	3623	359	62%	223
12	Condensed & Evaporated Milk	2023	33	80%	26
13	Cement, Hydraulic	3241	194	84%	163
14	Confectionery Products	2071	70	86%	60
15	Heating Equipment Except Electric	3433	389	71%	276
16	Metal Partitions & Fixtures	2542	400	80%	320
17	Industrial Inorganic Chemicals	2819	43	68%	29
18	Steam Engines & Turbines	3511	1,154	71%	819
19	Metal Stampings	3461	363	80%	290

[1] Source: "1968 Industrial Directory of the Commonwealth of Pennsylvania - 18th edition," Prepared by the Bureau of Statistics, Harrisburg, Pennsylvania, 1968.

[2] Source: "1967 Census of Manufactures, Pennsylvania," U.S. Department of Commerce, Bureau of the Census.

Actually, the rains arrived in York before it became necessary to curtail industrial water supplies in any of the plants to a point when production, and subsequently, payrolls were lost - but it could well have happened. For inputs to the simulation model, however, estimates were obtained from each of the 19 industrial firms personally contacted on the extent to which they would probably have to cut back production in the future for each of various levels of water curtailment. Cut-backs in production were found to be generally more, percentage-wise, than the reductions resulting in payrolls. For the SIC categories in the York Standard Metropolitan Statistical Area, which represents most of their large water-using industries, it was determined that the ratio of losses in payroll to corresponding production cut-backs, as represented by "Value Added by Manufacture," was 75%.[1] Consequently, in determining lost payrolls for the simulation model it was assumed that such losses amounted to 75% of production losses.

The specific steps taken as set forth in Table 6-1, to derive the figures for payroll losses by externally owned industries are as follows:

1. Table 6-1(a).

   Each of the companies interviewed was assigned a number (Column A). A brief description is given of its main product line (Column B) along with its appropriate SIC classification (Column C) as reported in the "1968 Industrial Directory of the Commonwealth of Pennsylvania - 18th Edition." The average number of employees during 1966 was also reported for each company (Column D) in the same publication.

   The percent of production employees to all employees was obtained from the "1967 Census of Manufactures, Pennsylvania" and is given in Column (E). The estimated number of production workers was obtained by multiplying the figures of Column (D) by Column (E), shown in Column (F).

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[1] This is an average figure weighted by the amount of water consumed by each of the SIC categories involved. Data on "value added" and man-hours were obtained from the 1958, 1963 and 1967 Census of Manufactures.

TABLE 6-1(b). Determination of Average Weekly Production Payrolls in 1966 For Externally Owned Large Water Using Companies in the York Area

Company Number (A)	Average Annual Wages Per Production Worker[1] (in 1967) (G)	Average Weekly Wages Per Production Worker (in 1967) Col (G) ÷ 52 (H)	Estimated Average Weekly Production Payroll (in 1966) Col (F) x Col (H) (I)
1	$ 5,840	$ 112	$266,448
2	7,050	136	29,648
3	6,050	116	147,900
4	5,740	110	94,270
5	5,600	108	36,828
6	6,330	122	21,472
7	6,229	120	119,640
8	5,826	112	5,712
9	5,826	112	12,544
10	6,750	130	47,710
11	6,750	130	28,990
12	5,000	96	2,496
13	7,313	141	22,983
14	4,072	78	4,680
15	5,925	114	31,464
16	6,050	116	37,120
17	6,933	133	3,857
18	6,726	129	105,651
19	7,729	149	43,210

[1] Source: "1967 Census of Manufactures, Pennsylvania," U.S. Department of Commerce, Bureau of the Census.

2. Table 6-1(b).

The average annual wage per production worker by various SIC classes was also obtained from the "1967 Census of Manufactures, Pennsylvania" by dividing the total of annual wages by the total number of workers. These annual wages are presented in Column (G).

The average weekly wages per production worker were obtained by dividing the annual wages in Column (G) by 52. The results are given in Column (H).

The average weekly production payroll in 1966 was determined by multiplying the number of production workers, Column (F), by the average weekly wage, Column (H). Results are given in Column (I).

3. Table 6-1(c).

Future anticipated production cut-backs, if water supplies are reduced by a given list of percentages (10% to 100%) are presented. This information was submitted by company personnel in response to questions posed at the interviews.

4. Table 6-1(d).

This table presents estimated losses in weekly production payrolls that result from production cut-backs tabulated in Table 6-1(c) as applied to average weekly production payrolls presented in Table 6-1(b), Column (I). A 75% reduction factor was applied to the resulting figure because production is assumed not to be proportional on a one to one basis with payroll; rather, payroll reductions are assumed to be 75% of water shortage induced production cut-backs.

The water company revenue lost to externally owned industry, represents a lost cash flow which normally comes into the community from an outside area. When the water company is forced by the shortage situation to restrict use, the industrial sector uses less water. This results in a loss of revenue to the water supplier, in this case The York Water Comapny. The magnitude of this loss is computed using information obtained from the Manager's Report of The York Water Company. This report is written annually by the General Manager to the Board of Directors and contains a large amount of information pertaining to the operations of the company. There is a section concerning cost and receipts of delivered water. Using the receipts per gallon from industrial water consumption and subtracting from this

TABLE 6-1(c). Anticipated Production Cut-Backs in Future If Water Supplies Are Reduced By:

Company Number (A)	10%	20%	30%	40% (J)	50%	100%
1	None	None	30%	40%	50%	100%
2	None	None	None	None	33%	100%
3	None	None	100%	100%	100%	100%
4	10%	20%	30%	100%	100%	100%
5	None	None	None	100%	100%	100%
6	None	None	None	None	None	10%
7	None	None	None	None	None	None
8	10%	20%	30%	40%	50%	100%
9	None	None	10%	13%	16%	33%
10	None	None	None	None	None	50%
11	None	None	10%	20%	30%	80%
12	None	None	30%	40%	50%	100%
13	None	None	None	None	None	None
14	10%	20%	30%	40%	50%	100%
15	None	None	None	10%	20%	70%
16	None	None	10%	20%	30%	80%
17	None	None	None	10%	20%	70%
18	None	None	None	None	None	50%
19	None	10%	20%	100%	100%	100%

TABLE 6-1(d). Loss In Weekly Production Payrolls[1], Col. (I) x Sub Col. (J) x 75%, If Water Supplies Are Reduced By:

Company Number (A)	10%	20%	30% (K)	40%	50%	100%
1	$ None	$ None	$ 59,950	$ 79,934	$ 99,918	$199,836
2	None	None	None	None	7,338	22,236
3	None	None	110,925	110,925	110,925	110,925
4	7,070	14,140	21,211	70,702	70,702	70,702
5	None	None	None	27,621	27,621	27,621
6	None	None	None	None	None	1,610
7	None	None	None	None	None	None
8	428	856	1,285	1,713	2,142	4,284
9	None	None	940	1,223	1,505	3,105
10	None	None	None	None	None	17,891
11	None	None	2,174	4,348	6,523	17,394
12	None	None	562	748	936	1,872
13	None	None	None	None	None	None
14	351	702	1,053	1,404	1,755	3,510
15	None	None	None	2,359	4,719	16,519
16	None	None	2,784	5,568	8,352	22,272
17	None	None	None	289	578	2,025
18	None	None	None	None	None	39,619
19	None	3,240	6,481	32,407	32,407	32,407
TOTALS	$ 7,849	$18,938	$207,365	$339,241	$375,421	$593,828

[1] Assuming Payroll Reductions Average 75% of Production Cut-Backs.

figure the operating cost per gallon associated with producing the water, the loss per gallon to the water company for undelivered water is obtained. In that 1966 was an abnormal year from the water company's standpoint, the data from the 1965 and 1967 Manager's Reports are used to calculate a loss of 15.45 cents per 1000 gallons for undelivered water. In simulating other drought conditions, the procedure is to ascertain the loss of water supplied to the externally owned industrial sector and use this information in conjunction with the unit loss derived for 1966 to calculate the total magnitude of the lost revenue.

LOCALLY OWNED INDUSTRY

In this category the profits and fixed costs lost[1] by locally owned industries are considered. When a local industry is forced to cut back production due to a restriction in its water supplies, it loses not only the profits on the goods it could not produce, but also any fixed cost that must be paid to maintain the plant facilities; for a community the size of York, these fixed payments are assumed to flow to outside interests. These fixed costs are ordinarily covered in the selling price of the goods, an illustration being rent or mortgage payments. Even if an owner is forced to shut down his plant entirely for a short period of time, he will still be faced with paying the fixed capital costs associated with all of his plant facilities. During such a period there will be no goods produced to provide a means for covering these costs; therefore, the local owners of industry will suffer a loss. The profits and fixed cost loss is determined by using the information collected in Table 6-2.

The specific steps taken in developing this table are as follows:

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[1] See previous footnote concerning externally owned industry.

TABLE 6-2(a). Estimated Annual Production Payrolls in 1966 for Internally Owned Large Water Using Companies in the York Area

Company Number (A)	Kind of Products (B)	SIC Class[1] (C)	Ave. No. of Total Employees[1] (D)	Percent of Production Employees To All Employees (in 1967)[2] (E)	Estimated No. of Production Workers Col(E)xCol(D) (F)	Average Annual Wages Per Production Worker (in 1967)[2] (G)	Estimated Annual Production Payroll (in 1966) Col(F)xCol(G) (H)
20	Paperboard Mills	2631	101	84	85	$7,050	$599,250
21	Bakery Products (Plant 1)	2050	188	63	120	5,516	661,920
22	Bakery Products (Plant 2)	2050	158	63	101	5,516	557,116
23	Cut Stone & Stone Products	3281	171	78[a]	133	5,955	792,015

[1]Source: "1968 Industrial Directory of the Commonwealth of Pennsylvania - 18th Edition," Prepared by the Bureau of Statistics, Harrisburg, Pennsylvania, 1968.

[2]Source: "1967 Census of Manufactures, Pennsylvania," U. S. Department of Commerce, Bureau of the Census.

[a]Based on SIC class 3270, because of U. S. Bureau of the Census concern about disclosing figures for individual companies.

1. Table 6-2(a).

   As in Table 6-1, each of the four internally owned companies interviewed was assigned a number (Column A). A brief description is also given of its main product line (Column B) along with its appropriate SIC classification (Column C) as reported in the "1968 Industrial Directory of the Commonwealth of Pennsylvania - 18th Edition." The average number of employees during 1966 was also reported for each company (Column D) in the same publication.

   The percent of production employees to all employees was obtained from the "1967 Census of Manufactures, Pennsylvania" and given in Column (E). The estimated numbers of production workers was obtained by multiplying the figures of Column (D) by Column (E) and are given in Column (F).

   The average annual wages per production worker by various SIC classes were also obtained from the "1967 Census of Manufactures, Pennsylvania," by dividing the total of annual wages by the total number of workers. Such average annual wages are presented in Column (G). The estimated annual production payroll is then obtained by multiplying the number of production workers in each firm (Column F) by the average annual production wage (Column G). The resulting payroll figures are presented in Column (H).

2. Table 6-2(b).

   To estimate profits and fixed costs for each of the large water-using establishments that are locally owned in the York area, it was necessary to begin with the number of production workers and payrolls as presented in Table 6-2(a). Next the annual value of shipments was estimated. This was done by obtaining the average percentage of production payrolls to value of shipments in 1966 by the appropriate SIC classes from the "1967 Census of Manufactures, Pennsylvania," as presented in Column (I). Applying these percentages to the estimated annual production payrolls to each of the four firms involved, it was possible to obtain the estimated annual value of shipments for these companies in 1966. These figures are given in Column (J).

   The next step was to derive reliable percentage figures on profits after taxes to sales. Such data, shown in Column (K), are presented in the "Quarterly Financial Report for Manufacturing Corporations," issued as a combined report of the Federal Trade Commission and the Securities and Exchange Commission.

TABLE 6-2(b). Estimated Profits and Fixed Costs in 1966 For Internally Owned Large Water Using Companies in the York Area

Company Number (A)	Production Payroll to Value of Shipments (in 1967)[1] (I)	Estimated Value of Shipments Col(H)÷Col(I) (J)	Profits After Taxes Per Dollar of Sales[2] (K)	Estimated Profits After Taxes Col(J)xCol(K) (L)
20	18.3%	$3,274,590	4.8%	$157,180
21	14.3	4,628,811	2.6	120,349
22	14.3	3,895,916	2.6	101,294
23	17.0	4,658,912	5.3	246,922
				$625,745

[1]Source: "1967 Census of Manufactures, Pennsylvania," U. S. Department of Commerce, Bureau of the Census.

[2]Source: "Economic Report to the President," January, 1970.

TABLE 6-2(b)-Continued. Estimated Profits and Fixed Costs in 1966 for Internally Owned Large Water Using Companies in the York Area

Value Added by Manufacture (less Production Payroll) to Value of Shipments (in 1967)[1] (M)	Estimated Fixed Costs Col(J)xCol(M) (N)	Profits Plus Fixed Costs Col(L)+Col(M) (O)	Company Production Workers (from Col(F) (P)	Profits Plus Fixed Costs Per Production Worker Col(O)÷Col(P) (Q)
35.2%	$1,152,656	$1,309,836	85	$15,410
41.8	1,934,843	2,055,192	120	17,127
41.8	1,628,493	1,729,787	101	16,124
30.3	1,411,650	1,658,572	133	12,470
	$6,127,642	$6,753,387	439	$15,384

[1]Source: "1967 Census of Manufactures, Pennsylvania," U. S. Department of Commerce, Bureau of the Census.

[2]Source: "Economic Report to the President," January, 1970.

By applying these percentage figures to the estimated value of shipments as set forth in Column (J), the estimated profits after taxes for each company were calculated. These figures are presented in Column (L).

Because figures on fixed costs for each of the four establishments involved were not readily available, they were estimated from official census data. This was accomplished by subtracting production payroll from the value added by manufacture. The resulting figure should include mortgage or rent payment, plus salaries and other expenses for the plant administrative and maintenance staff which would undoubtedly be functioning, even during a fairly prolonged water shortage.

By relating such figures to the value of shipments as presented by the appropriate SIC classes in the "1967 Census of Manufactures, Pennsylvania," the percentages are then calculated as set forth in Column (M).

It is then possible to apply these percentages to the estimated value of shipments (Column J) and obtain an estimate of fixed costs which are presented in Column (N). Profits plus fixed costs (Column L plus Column N) are given in Column (O).

In order to relate the total amount of profits and fixed costs to the production worker, Column (O) has been divided by the number of production workers (Column P) and the results shown in Column (Q).

DOMESTIC SECTOR

The consumer surplus[1] that is lost by the domestic sector is the fourth source of loss to the study area. In order to evaluate the magnitude of this loss the demand curve for residential water is needed. Figure 6-2 illustrates this concept. The portion of the area marked consumer surplus is the loss suffered by the domestic sector when its demand (supply)

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[1] One can integrate the demand curve to the equilibrium point to derive total utility. Total cost is the price at equilibrium times the volume used. The difference is the consumer surplus. When there is a forced shortage, one can integrate the demand curve from the forced lower limit to the equilibrium point and difference the associated cost to determine lost consumer surplus; this quantity is estimated in this report and is assumed to be the domestic loss.

is decreased by the water supplier. This technique is used to evaluate the losses to the domestic sector during a period of restricted use.

In developing the aggregate demand curve for the York area, the work done by Howe and Linaweaver on residential water demand is used. In this work it is suggested that the demand curve be disaggregated into two portions, the sprinkling demand and the domestic demand, if an increase in consumption is prevalent in the summer months. This is the case in York and for the residential sector two demand curves are developed. In the York area there is an additional important factor involved; only approximately one-third of the residential customers are metered; the remaining ones are on a flat rate. Fortunately, the two classes of residential are well divided geographically and demographically. The flat rate customers are all located in the City of York, while the metered customers generally represent the suburbanites. For the purpose of the study the two classes of customers are considered separately, but only a price-demand relationship can be developed for the metered area. It is assumed that the flat rate customers fall on the derived demand curve for the purpose of estimating consumer surplus.

The sprinkling demand curve is calculated by using Howe and Linaweaver's equation

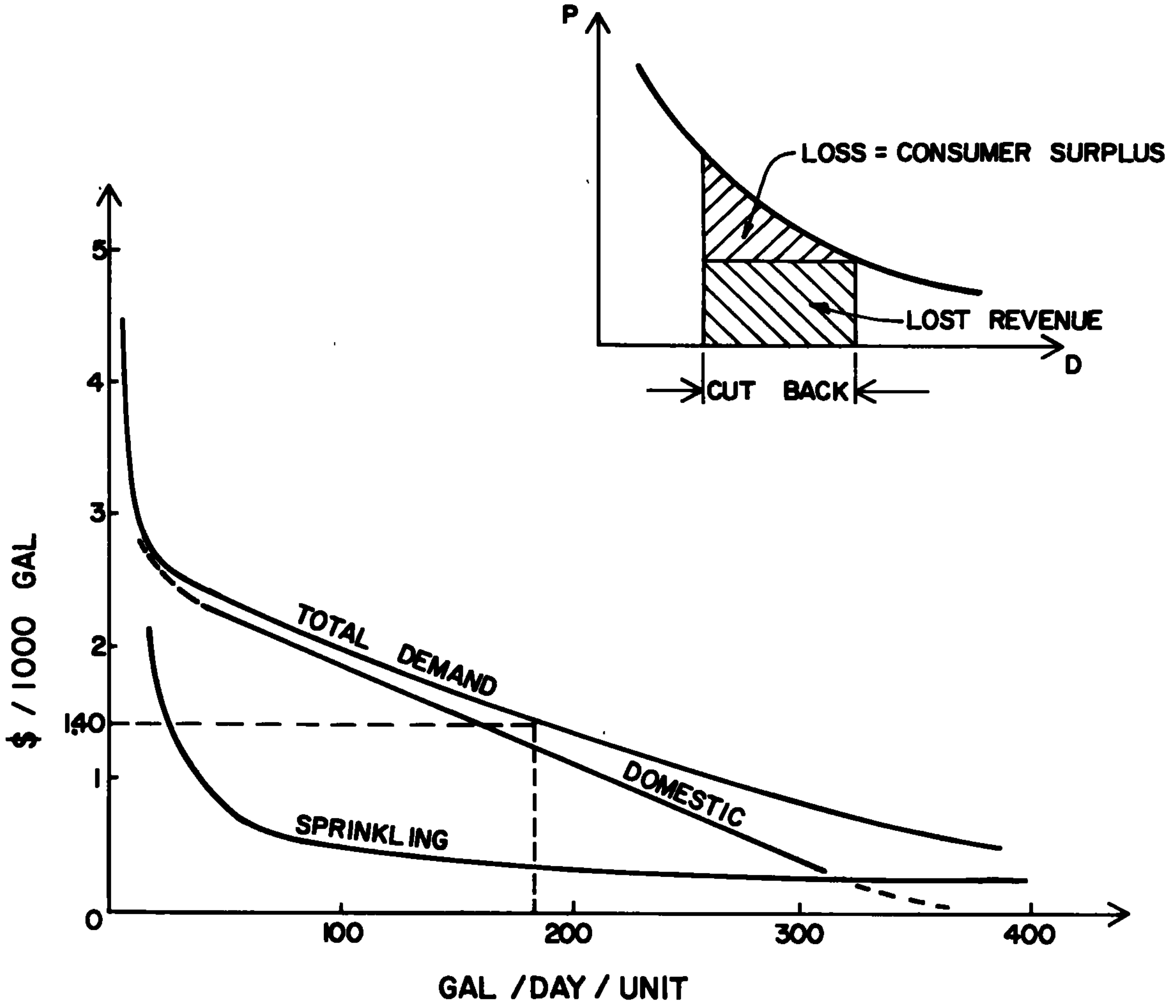
$$q_s = A \cdot b^{-0.793} (w_s - 0.6r_s)^{2.93} \gamma^{1.45} p_s^{-1.57} , \qquad (6\text{-}3)$$

where,

A = coefficient to fit curve to specific area,

b = irrigable area per dwelling unit (acres)[1],

[1] Within the framework of this report this value is estimated using today's data and is assumed constant. A refinement would be to project irrigable area as a function of time.



	METERED	FLAT RATE *
SPRINKLING	21	28
DOMESTIC	160	334
TOTAL	181	362

* AVERAGE $.42/1000 GAL

FIGURE 6-2
DOMESTIC DEMAND

p_s = marginal charge for water (cents/1000 gal.),

q_s = average summer sprinkling demand (gal/day/dwelling unit),

γ = market value of dwelling unit ($1000),

r_s = summer precipitation (inches), and

w_s = summer potential evapotranspiration (inches).

For the York area, q_s is determined by taking the difference in the average monthly metered demand for the sprinkling and non-sprinkling months. For the purpose of this study the sprinkling months for the York area are June, July and August. The values and the source of the data that are used to obtain the remainder of the variables for the metered area are:

VARIABLE	VALUE	DATA SOURCE
b	.3(AC)	York County Planning Commission
p_s	140($1000 gal)	The York Water Company rates
q_s	21(gal/day/unit)	The York Water Company records
γ	20.85($1000)	U. S. Bureau of the Census tract data
r_s	5.0(inches)	The York Water Company records
w_s	12.0(inches)	Climatic Atlas

Although most of these variables were obtained directly, some mention should be made of how the values of r_s and γ were determined. The amount of rainfall, r_s, was set at 5.0 inches for the summer months depicting a dry year, which is normally the case in a water supply shortage. The value of the housing, γ, was calculated from data in the 1970 U. S. Census information for the York area. γ was taken to be a weighted average house value, where the numbers averaged were the midpoints of the various value intervals reported in the census information, and the weights were the number of dwellings in each interval.

Substituting these values into Equation 6-3 it is possible to determine a value for A. Having the value of A defines the demand sprinkling function as

$$p = 2136\ q_s^{-.6369} \quad . \tag{6-4}$$

This allows the computation of the consumer surplus when the water company restricts the non-essential use of water. In the York area the sprinkling loss is .12 \$/day/unit. The simulation uses this unit loss, the total number of metered plus flat rate units and the number of days of restricted use to compute the total sprinkling loss.

The domestic portion of the consumer surplus loss will only occur in an extreme situation. The last use of water to be restricted is assumed to be the domestic demand. Howe and Linaweaver's work was again used to determine the loss of domestic consumer surplus. The general equation governing the price-demand relationship for domestic use is

$$q_d = C + 3.47 \cdot \gamma - 1.30\ p_s . \tag{6-5}$$

where,

C = coefficient to fit area,

p_s = price of water (cents/1000 gal),

q_d = domestic demand (gal/day/unit), and

γ = market value of housing (\$1000).

The winter average monthly demand is assumed to represent the domestic demand and is calculated to be 200 gallons per day per dwelling unit.

Having determined all other values, the value of C is computed to be 270. This yields the price-demand function to be

$$p_s = - .769\ q_d + 263. \qquad (6\text{-}6)$$

From this equation and allowing a thirty percent reduction in domestic demand (160 gallons/day/unit); it is possible to calculate a consumer surplus of .89 cents/day/dwelling unit. The simulation uses this unit loss value, the number of dwelling units and the total number of days the restriction is applicable to determine the domestic loss.

Totaling the values of the lost consumer surplus due to sprinkling and domestic use restrictions yields the total consumer surplus in the face of drought restrictions. The final demand curves, sprinkling and domestic, and the aggregate demand curve is shown in Figure 6-2.

STOCK LOSS

Determining the non-replenished stock losses to all sectors is not a simple problem. However, by making use of the information gained from personal interviews, telephone interviews and the residential questionnaires, it is possible to assess the situation. The commercial and municipal sector, including The York Water Company, report no measurable stock losses. Interpreting the residential questionnaires and talking to residents of the York area led to the conclusion that any stock losses of lawns or shrubs were replenished within the local sector and were not a loss outside of the area. The industrial operations interviewed could not attribute any non-replenishable losses directly to the drought. In fact, the only large stock loss was felt by one nurseryman. Due to the restriction placed on sprinkling he lost a large amount of young plants, shrubs and trees valued at approximately $30,000. It turned out to be a freak incident and no other significant stock losses could be found. Therefore, it is assumed in the case study using the simulation model that any stock losses in the area will be replaced locally and should not be counted in the total loss to the area.

By summing the five major sources of loss to the area, it is possible to determine the total magnitude of the regional loss due to any simulated shortage condition.

7. ANALYSIS OF THE CASE STUDY

The objectives of this chapter are to describe the details of the York simulation model and to present the results of a sensitivity analysis that identifies important parameters. This chapter deals with the simulation specifically used in the York area; however, with only minor modifications the computer program can be used in any urban area to simulate water shortage conditions.

The simulation logic has a relatively simple structure. For a given reservoir storage, a set of hydrologic conditions with their associated probabilities are used to compute the daily supply available for municipal withdrawal. The demand is calculated in five-year increments for a fifty-year planning period. Next a water balance is performed on the supply and demand for a given year for each hydrologic condition and the reservoir releases required to meet the demand are tallied. The daily reservoir level is also calculated. When the reservoir reaches certain critical levels, a systems operating rule is instigated which either increases supply by importing water or decreases demands by imposing restrictions on water use. An economic portion of the simulation determines the regional dollar losses incurred by the study area as a result of the water supply importations or restrictions. Each hydrologic condition results in different losses. Each loss is multiplied by the probability of the associated hydrologic condition to determine the risk. The risks associated with the complete set of hydrologic events are accumulated to determine the total risk for the given year of a water supply shortage. The simulation repeats this process in five-year steps for the increasing demands until it reaches the year 2020 and produces the information shown in solid lines in Figure 7-1. This figure shows the yearly risk of water supply shortages in the York area at five-year intervals. The yearly risks for the years between the five-year time step are obtained by linear interpolation.

The dotted lines in Figure 7-1 are the results of the linear interpolation. In order to reduce the information gained from this technique to a single number the model calculates the present worth of the total yearly risks over the fifty-year planning period. Each reservoir storage level has an associated present value of risk. The model then determines the cost associated with construction of a reservoir of the size selected. By allowing the simulation to consider various size reservoirs, a figure such as 7-2, which should prove useful to a planner, can be prepared. The complete computer algorithm and documentation is given in the Appendix.

SIMULATION COMPONENTS

In the simulation process there are four major components: hydrology, demand, system operation and economics. This section describes these components as they are developed for use in the York simulation. The hydrology is a major component of the analysis. Figure 1-2 shows the surface water supply network of York, Pennsylvania. The pumping station which withdraws the water supply for the area is located directly downstream from the confluence of the east and south branch of the Codorus Creek. There are two major sources of data relating to the hydrologic variables.

One is the network of U. S. Geological Survey gages in the area and the other is the record of the streamflow conditions in 1966 of The York Water Company. The USGS records are not accurate because of a lack of correction over the complete length of record for both reservoir releases and the pumping station withdrawal. However, the water company has an accurate and complete account of the natural streamflow for the period May 1, 1965 to April 10, 1966, the lowest flow period of recent record. This record is used as a basis for calculating daily fluctuation in streamflow under all other flow conditions.

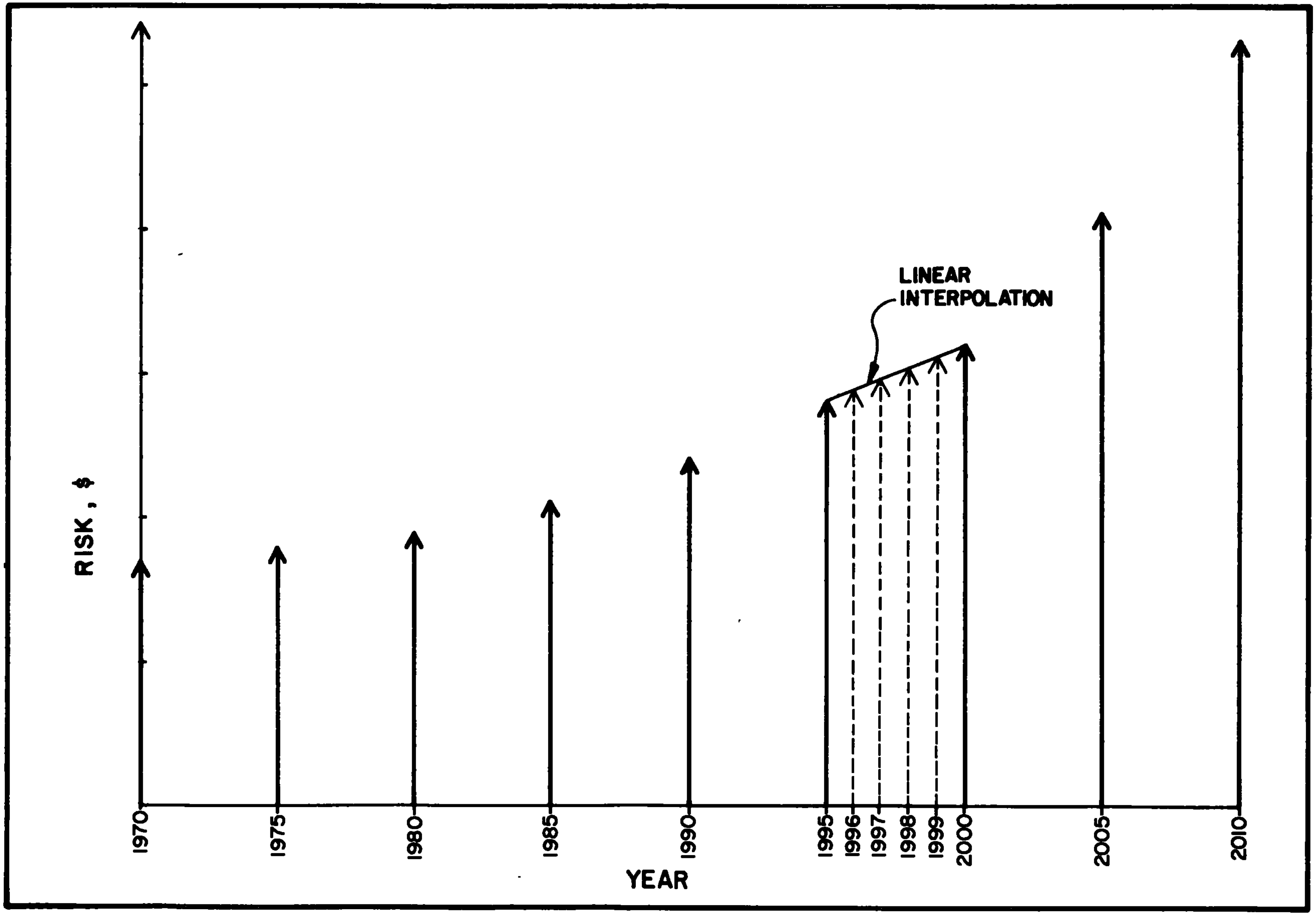


FIGURE 7-1
RISK TIME STREAM

The gage is located below the pumping station and provides the historical hydrologic information. Since the summer months are low streamflow months for York, the average daily flow for the period June through September is selected for analysis. The standard n + 1 plotting position technique is used to develop Figure 7-3. From the figure the probability of any given average summer flow condition can be found. In the case of York, only the lower flow conditions are of interest in studying water shortages.

Therefore, Table 7-1 is developed to represent the spectrum of hydrologic events that are of interest. The five summer mean class mid-points (90, 70, 50, 30, 25; all cfs) shown and their associated probabilities (.17, .22, .22, .096, .037) are used in conjunction with the 1966 daily flow record to generate the hydrologic component of the analysis. By multiplying the 1966 daily summer record by a ratio

$$\frac{U_x}{U_{1966}},$$

where U_x is the appropriate summer mean presented in Table 7-1 and U_{1966} is the daily summer mean flow for 1966 (31 cfs), a complete trace of daily flow at the pumping station is generated which is assumed to have the probability associated with U_x. By repeating this process for all values shown in Table 7-1, a spectrum of five daily streamflow records is developed for use in the simulation.

To compute streamflow inputs to the reservoir it is necessary to know the flow in the East Branch above the impoundment. This is done by using flow records from the gage on the East Branch and flow records below the pumping station. The historical flow ratio of the East Branch flow to the South Branch flow is .457. This ratio is used to correct the pumping station flows to represent reservoir inputs.

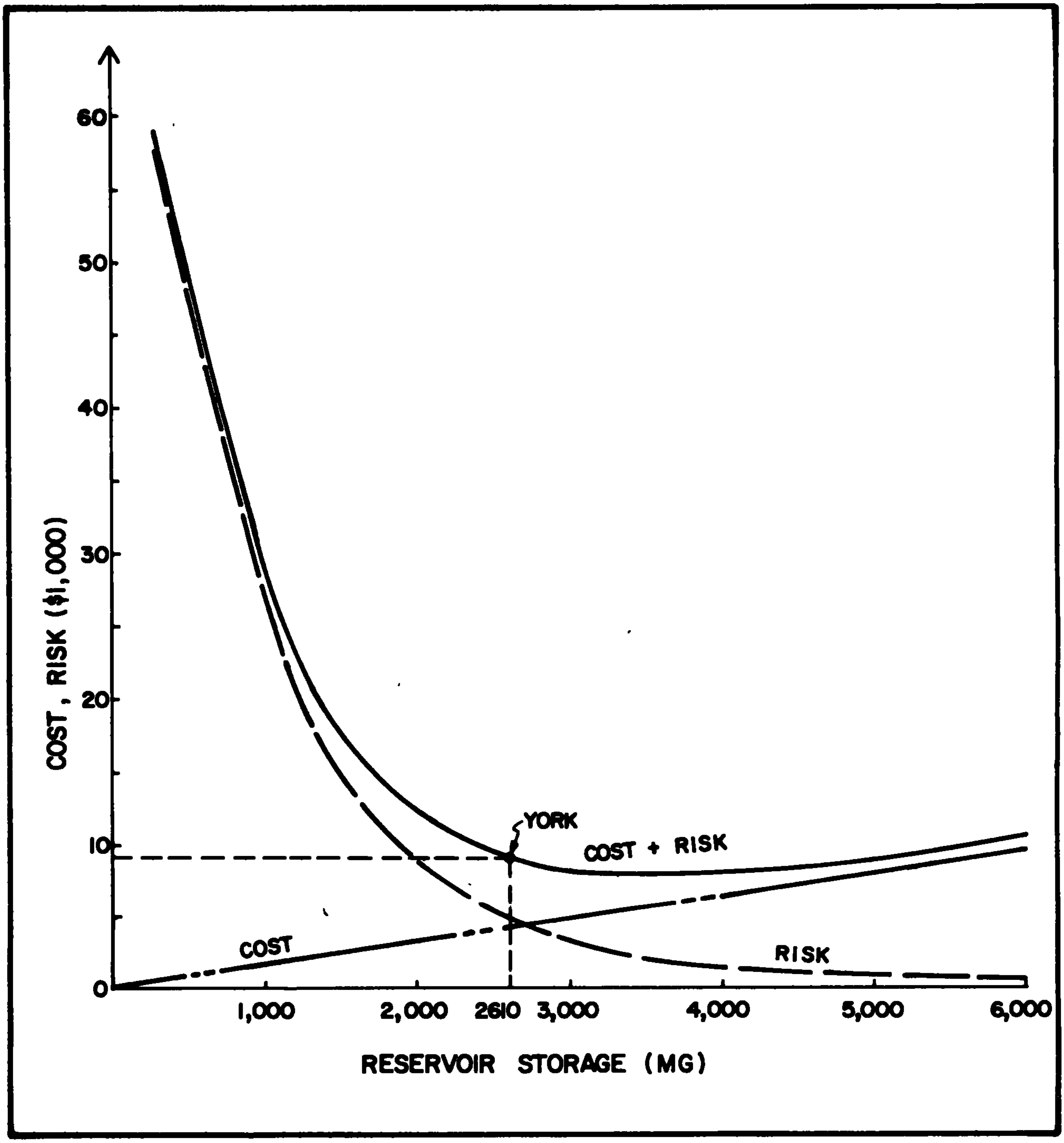


FIGURE 7-2
PRESENT WORTH ANALYSIS

TABLE 7-1. Low Flow Probability Analysis

1 Q, cfs	2 Class Midpoint cfs (U_x)	3 Probability of Less Than U_x	4 Probability of Class Interval
100		0.7100	
	90		.1700
80		0.5400	
	70		.2200
60		0.3200	
	50		.2200
40		0.1000	
	30		.0962
20		.0038	
	25		.0037
10		.0001	

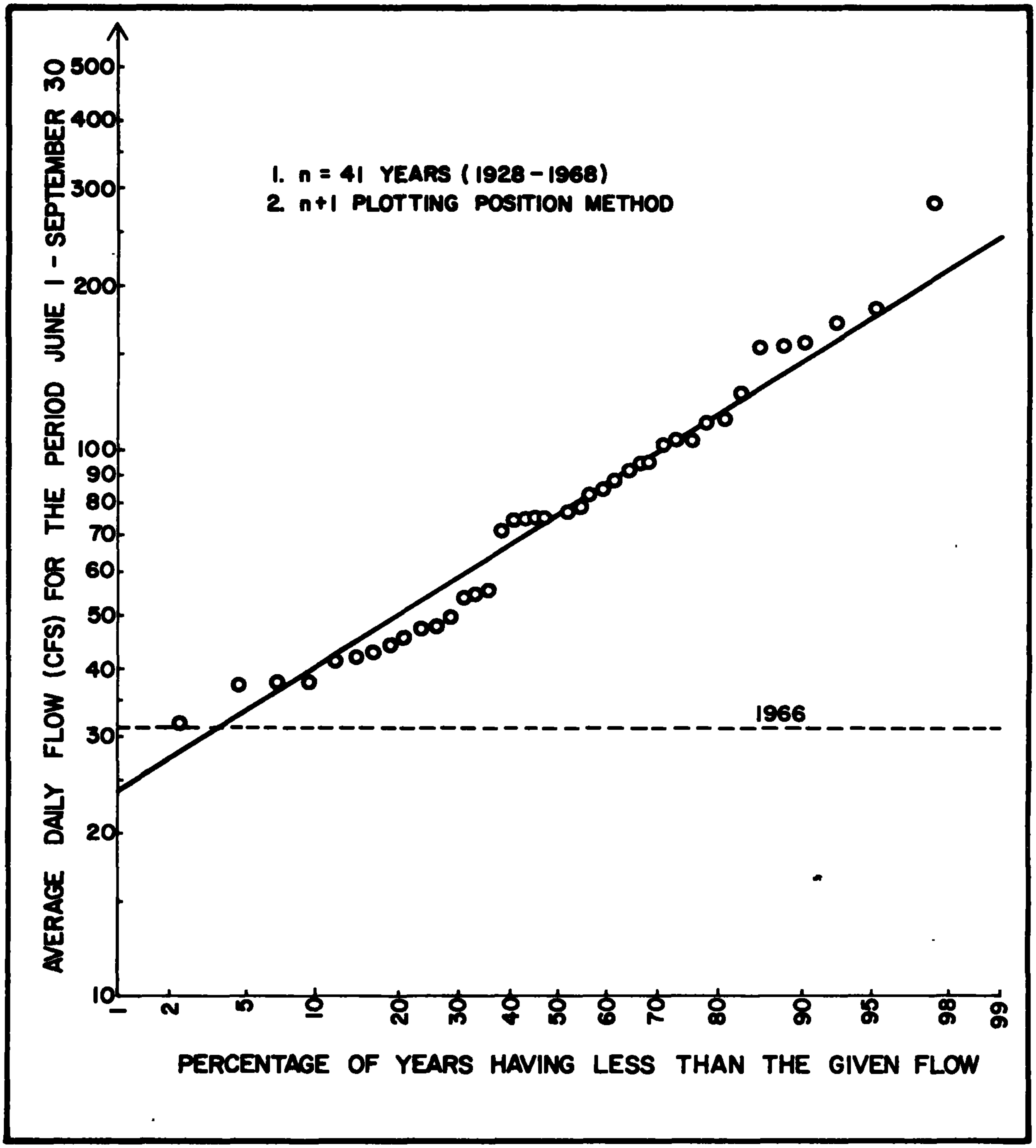


FIGURE 7-3

FINAL HYDROLOGY

The demand component of the simulation uses data taken from an engineering report to The York Water Company. This report is dated 1967 and the information contained in the records of The York Water Company and the 1970 Census of Population since this time are used to supplement these data. Figure 7-4 shows the anticipated growth per capita consumption of water. This represents a growth rate of about one-half of a percent per year. When this information is used in conjunction with the population projection shown in Figure 7-5, it is possible to project the water consumption for the region. A plot of this consumption until the year 2020 is shown in Figure 7-6. The demand projections are used in the study in order to be able to predict the economic impact of water shortage conditions in the fifty-year planning period.

To account for the variance in the average demand throughout a year, the average daily consumption is multiplied by factors that reflect the monthly fluctuation in the average daily consumption. Table 7-2 shows the factors that are derived on a monthly basis for the York area. They are determined by using ten years of consumption records. This allows a more accurate demand estimate for within year periods.

The systems operating rule is a major component of the simulation. In the York area the actions taken to increase supply or decrease the demand for water are initiated by the manager of the water company. His actions are prompted mainly by the amount of storage in the reservoir. This information is incorporated into the simulation, thus, certain calculations are performed based on the level of the reservoir. This decision schedule is a function of the reservoir level and is considered to be a system operating rule.

Table 7-3 presents the critical reservoir levels and the corresponding actions and their effects on supply and demand that are used in

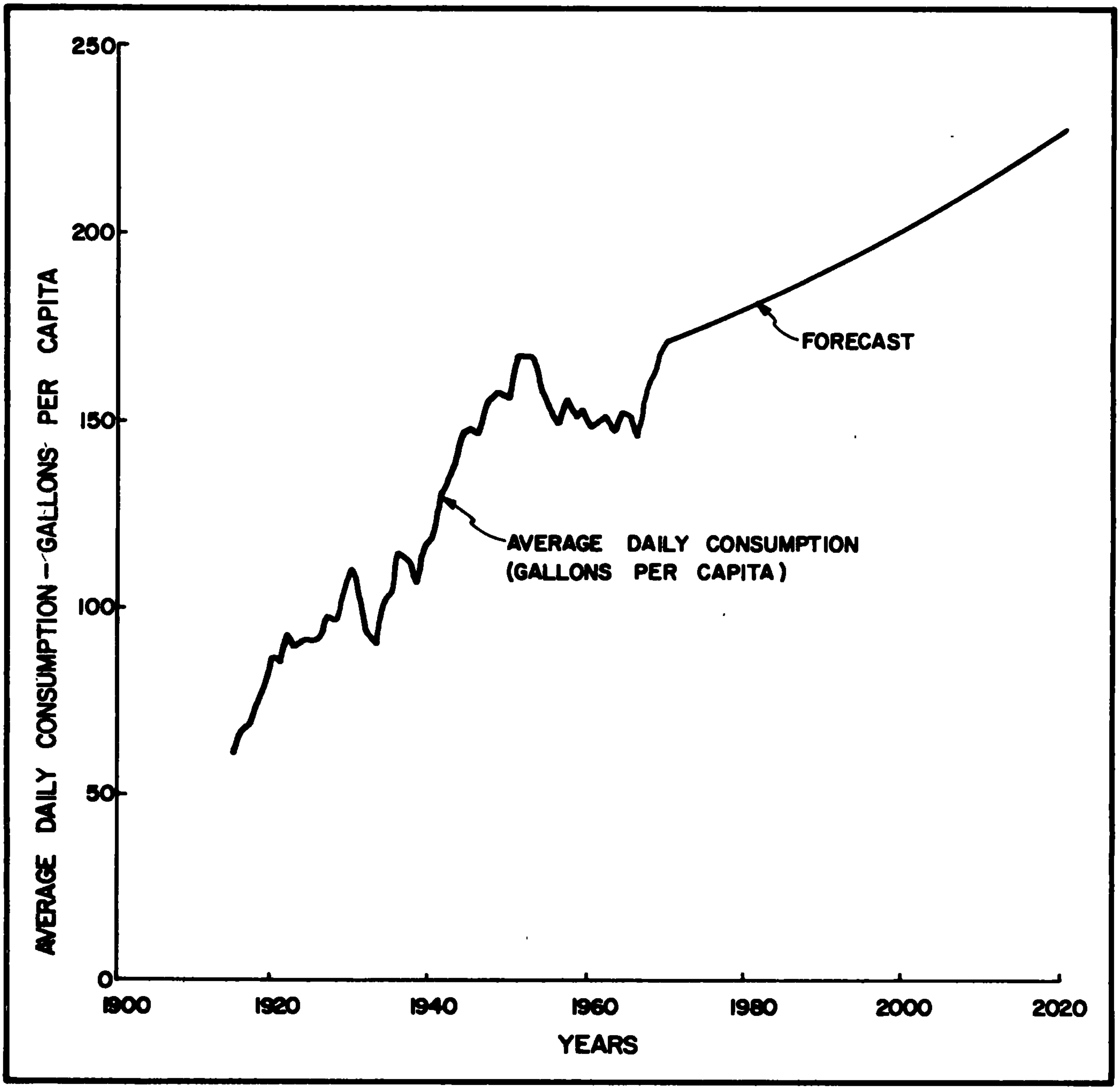


FIGURE 7-4

PAST AND ESTIMATED FUTURE CONSUMPTION RATES

(GALLONS PER CAPITA PER AVERAGE DAY)

TABLE 7-2. Factors To Distribute Average Yearly Demand On A Monthly Basis

Month	Factor To Be Applied To Yearly Mean To Obtain Monthly Mean
January	.9648
February	.8892
March	.9648
April	.9360
May	1.0212
June	1.0968
July	1.1052
August	1.1112
September	1.0176
October	.9876
November	.9324
December	.9672

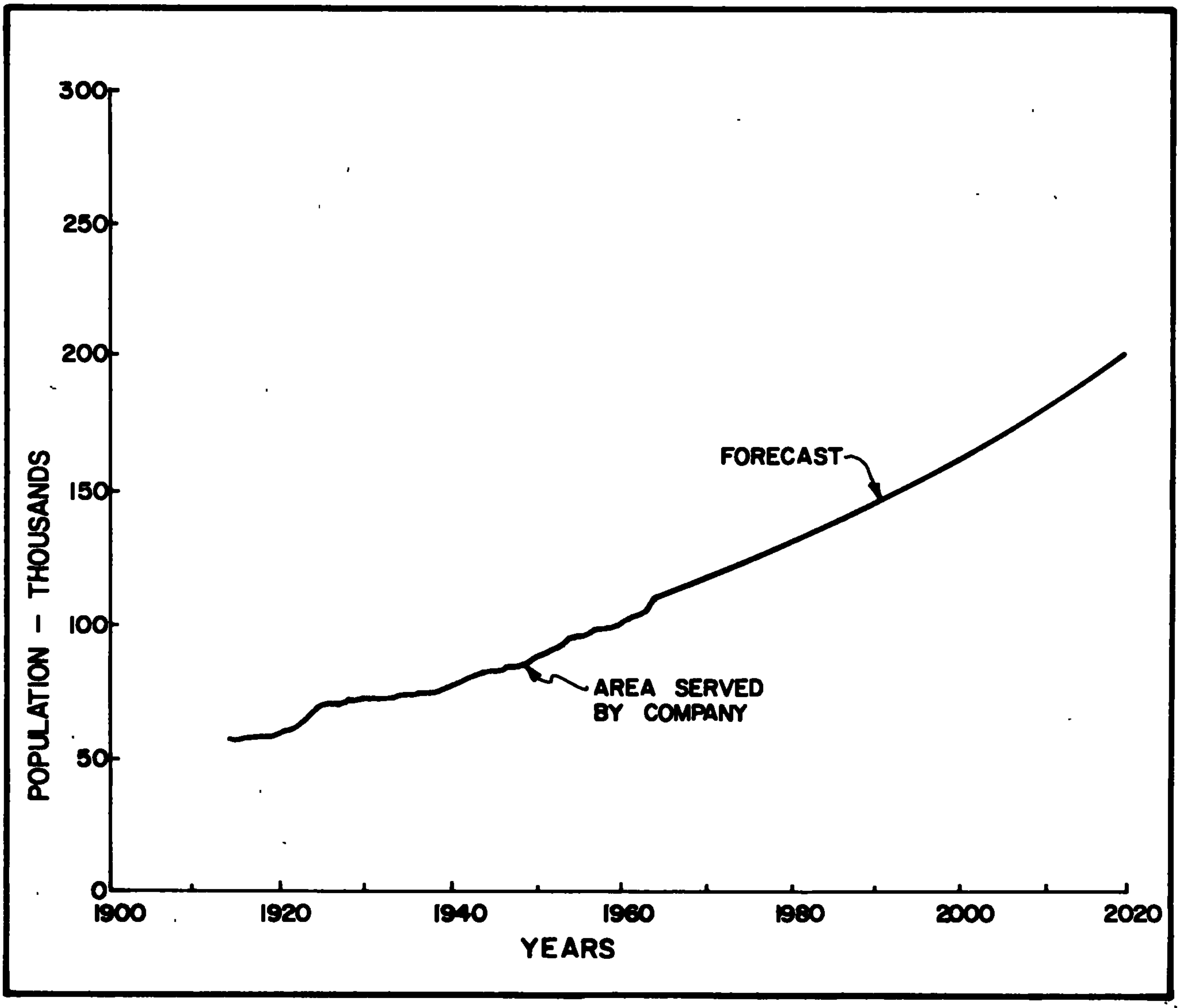


FIGURE 7-5

PAST AND ESTIMATED FUTURE POPULATIONS

(STATE OF PENNSYLVANIA, YORK COUNTY,
AREA SERVED AND THE CITY OF YORK)

TABLE 7-3. System Operating Rule

Reservoir Level (% of full)	Resulting Actions	Effect On Supply Or Demand
90	Issue Voluntary Restriction on Water	Reduce Industrial* and Domestic Demand to 90% of Original
70	Issue Mandatory Restriction on Water	Reduce Industrial and Domestic Demand to 80% of Original
	Start Importing Water by Trucking and Using Quarries	Increase Supply by 3.9 MGD
25	Supply Industries on Only One Shift of Workers	Reduce Industrial Demand to 50% of Original
20	Start Building Emergency Pipeline to Susquehanna River	Twenty Days After Start Up, Increase Supply 8.5 MGD
15	Shut Off All Supply to Industry	Industrial Demand Set Equal to Zero
10	Impose Additional Restrictions on Domestic Use	Reduce Domestic Demand to 50% of Original

*Industrial refers to all categories other than domestic.

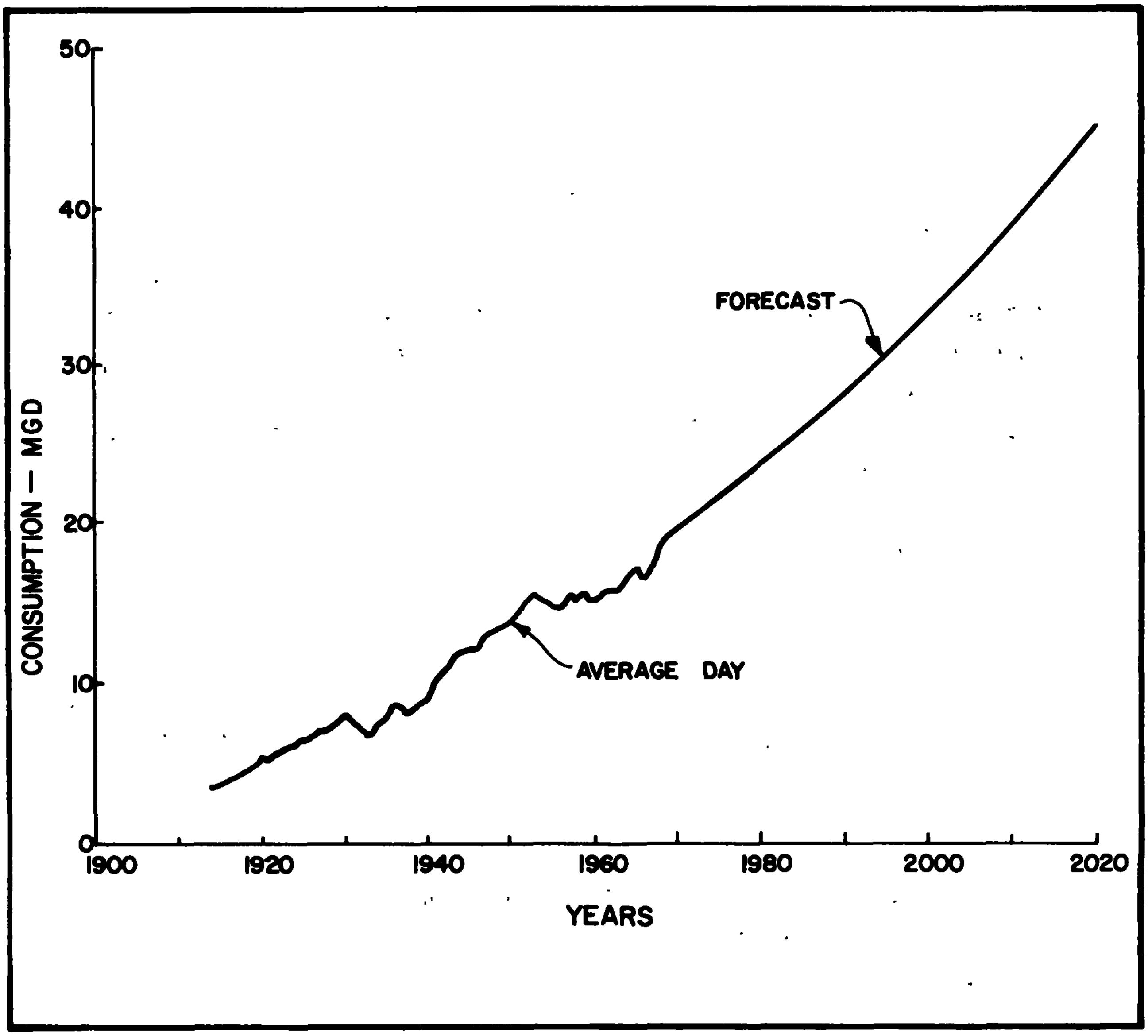


FIGURE 7-6
PAST AND ESTIMATED FUTURE CONSUMPTION

the simulation. It is important to further explain three aspects of the operating rule as it was adopted to apply directly to the York situation. First, the trucking operation to import water is intended to be only a very short run operation; therefore, when the expenses to The York Water Company reach a level commensurate with that spent in the 1966 shortage condition, the trucking operation is stopped and the supplemental supply is reduced. The second unique feature of the operating rule is the delayed increase in supply from the pipeline to the Susquehanna River due to the time required for construction. In 1966, it was estimated that by working at full capacity a large field crew could build the pipeline in twenty days. Therefore, the simulation does not bring the supply on line until twenty days after the order to build it (20% reservoir capacity) has been issued. The third important aspect, which is not shown in Table 7-3, is the filling portion of the operating rule. When streamflow is replenished by rainfall and the reservoir is filling, all restrictions and importations are lifted when the reservoir storage exceeds 50% of capacity.

If any of the actions are taken according to the systems operating rule, demand contraction causes financial losses to occur. The simulation computes the resultant economic losses and converts them to risks. Chapter 6, Loss Functions, gives a complete description of how the various losses are determined. Shown in Table 7-4 is a summary of the economic losses in the York area. The simulation model uses this economic information to generate the total losses. There is one additional loss not presented in the Table, but which is used in the simulation; at 20% reservoir capacity, the water company must build the pipeline to the Susquehanna at an estimated construction cost of $650,000.

In order to use the foregoing loss information in the simulation it is necessary to know two projected quantities: the number of units supplied

TABLE 7-4. Summary of Economic Losses

Reservoir Capacity (% of capacity)	Cost of Imported Water ($/1000 gal)	Loss of Production Payroll ($/week/ worker)	Water Company Revenue Lost (¢/1000 gal)	Lost Profits and Fixed Costs ($/year/ worker)	Consumer Surplus of Domestic Sector ($/unit/day)
90	0	0	15.45	0	.01
70	5.80 trucked .58 quarry	0	15.45	0	.12
25	5.80 trucked .58 quarry	23.09	15.45	1904.58	.12
15	5.80 trucked .58 quarry .03 Susquehanna	66.14	15.45	9951.32	.12
10	5.80 trucked .58 quarry .03 Susquehanna	66.14	15.45	9951.32	.13

by The York Water Company at any time in the fifty-year planning period and the number of production workers employed at any time by locally and externally owned industries.

The total number of units served by The York Water Company at any time is found by adding the number of flat rate and metered customers. The projected number of flat rate and metered customers for the next fifty years is shown in Figure 7-7. Number of production workers is calculated by assuming that the ratio of workers to total population stays the same over the fifty-year planning period. This allows a direct calculation from the population projection by making the assumption that the population mix remains constant.

In the economic portion of the simulation the computation of reservoir cost is performed. This cost is based on the capacity of the reservoir and is broken into two components, cost of land and construction cost. The construction cost is determined to be approximately $375 per acre foot of storage, based upon information contained in the Corps of Engineers Potomac River Basin Report. In York, the land cost on the reservoir project completed in 1967 was $2500 per acre. These two values, when coupled with the estimates of the amount of land required for varying size reservoirs, are used as the basis for calculating the total cost of the reservoir selected for the simulation.

SENSITIVITY ANALYSIS

In order to evaluate which parameters have the largest effect on the risks associated with a water supply shortage, a sensitivity analysis is performed with the model. Nine important parameters are individually varied over the range ± 10% while all others are held constant. A small reservoir size is used so that all loss functions need to be employed. Table 7-5 shows the parameters ranked in order of their effect on the simulation results and Figure 7-8 illustrates this information.

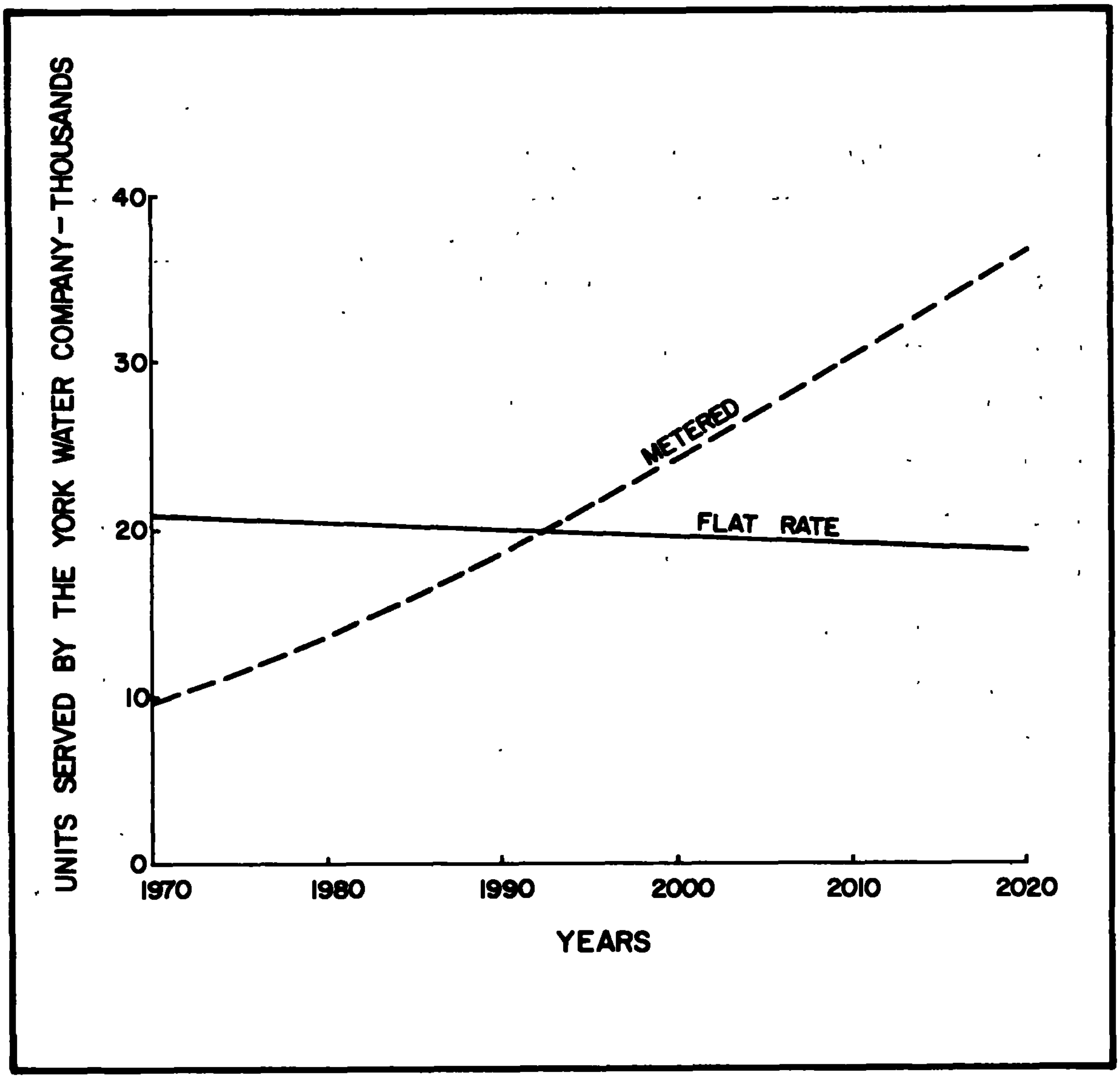


FIGURE 7-7

NUMBER OF WATER COMPANY SERVICES

TABLE 7-5. Results of Sensitivity Analysis

Parameter	Percentage Change in Risk	
	+10% Parameter	-10% Parameter
1. Per Capita Demand	+ 18.98	- 17.83
2. Hydrology	- 13.1	+ 15.2
3. Interest Rate	- 10.7	+ 12.7
4. Industrial Losses	+ 8.0	- 8.0
5. Population	+ 7.9	- 7.9
6. Susquehanna Pipeline	+ 1.2	- 1.2
7. Import Costs	+ 1.1	- 0.8
8. Domestic Losses	+ 0.7	- 0.7
9. Critical Reservoir Levels	+ 0.3	- 1.2

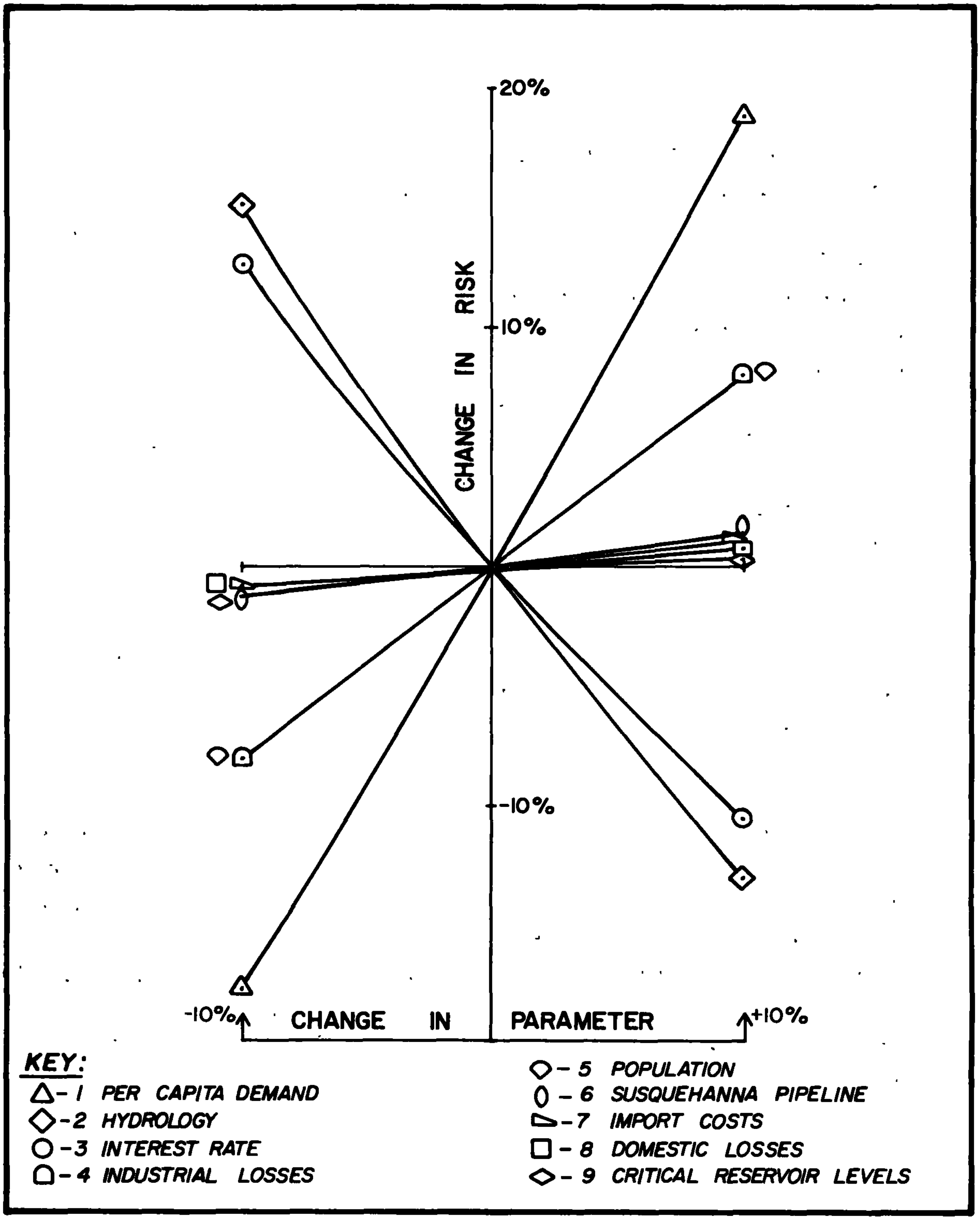


FIGURE 7-8
RESULTS OF SENSITIVITY ANALYSIS

Only five of the parameters show a marked influence on the result. The estimate of the future per capita demand is by far the most sensitive variable and deserves much attention in future work. The second ranking variable, hydrology, points out the need for additional studies concerning the probabilities of droughts of various duration and magnitude. Interest rate, as expected, is an important factor, but is perhaps the parameter over which one has the least control. Industrial losses are the only loss term that has an appreciable effect on the risks. However, this term includes the lost fixed costs and profits of locally owned industries, lost water company revenues to externally owned industries and the loss of payroll to local residents. Of these, the domestic payroll term is by far the most influential one.

Most of the losses due to water shortage in the service area are directly proportional to the population, which is used to predict demand, number of units served and number of production workers employed by both externally and locally owned industries. Therefore, it is not surprising to find population having a rather large effect on risk.

It should be pointed out that the low ranking of the manager's decisions, as reflected by the small effect that the critical reservoir levels have on the risks, can be misleading. This analysis is carried out on a very small reservoir in order that all economic losses are incurred. This means that a 10% change in critical reservoir levels will in this case have a very small effect on the risks. It should be noted that in large reservoirs this would not be the case, and in all likelihood, these decisions would become very important.

The sensitivity analysis should be used as an indicator of the important variables which should be carefully analyzed during the data collection phase of any future study.

APPENDIX

DOCUMENTATION OF COMPUTER MODEL
DEVELOPED TO EVALUATE THE
"ECONOMIC RISK OF WATER SUPPLY SHORTAGE"

DESCRIPTION OF COMPUTER MODEL

INTRODUCTION

A computer simulation program has been written in FORTRAN IV language for the PDP-10 machine and can easily be adapted for use on other computers. The procedure models the economic losses incurred by an urban area during a water supply shortage. The model was used to study the means by which an urban area can estimate the risks involved in a water shortage, and thereby devise ways to minimize this risk. The model can be readily applied to many urban areas.

GENERAL DESCRIPTION OF THE MODEL

The basic elements of the model are a stream which furnishes the main water supply to the urban area, a reservoir, a "water company" which manages the system, and alternate water supply sources such as rivers and wells. Inputs to the program consist of the projected population of the area for the time period being simulated, the water demand expected for this period, the hydrology of the supply stream, the reservoir storage, data describing how the system is to be managed, and economic losses contingent on various shortage conditions.

The area being modeled is divided economically into four sectors: municipal, industrial, commercial, and domestic. The model calculates the economic losses incurred by each of these four sectors during a water shortage. The economic losses to the area during a water supply shortage are taken as those losses from each sector which are not gained or "made up" by another sector.

For each year simulated the program performs a daily cycle. Each day the model compares the supply for that day with the demand for that day. If the supply is greater than the demand, no special action is needed, and the model proceeds to the next day. On a day when the supply is less than the demand, the water management routine is called. This routine simulates the management of the system by the local water company. The routine examines the level of the reservoir and determines which restrictions, if any, should be imposed on the different sectors. As the reservoir draws down to certain critical levels (specified on input cards) the restrictions are increased in severity. The effect of the restrictions on the system is twofold. First, the demand for that day is reduced. Second, economic losses are incurred by the different sectors. These losses are calculated and added to the total losses for that year.

Control is now returned to the main program which compares the new reduced demand for that day with the supply for that day. If the supply is still less than the demand, water is drawn from the reservoir, and alternate water sources are called upon if necessary. The model now proceeds to the next day. When the reservoir begins filling and has reached a certain level, the restrictions are lifted and the water management routine is bypassed. After the model has completed the daily cycle, the total economic losses for that year are stored for later use and the model proceeds to the next year to be simulated.

APPLICATION OF THE MODEL

The model has been used in a case study of York, Pennsylvania in order to ascertain an optimum reservoir storage which would minimize the economic risk of a water supply shortage. Population and water demands from 1970 to 2020 (at five year intervals) are stored in the program. A given reservoir storage is specified. Using this storage, the period from 1970 to 2020 is simulated under five different levels of streamflow. For each year simulated, the economic losses at each of the five flow levels are calculated and converted to economic risk by multiplying by the probability of that flow occurring. The five risks are summed to form a total yearly risk. The sum of the yearly risks (in present worth with base year 1970) from 1970 to 2020 is taken as the risk at that particular storage level. This procedure is applied to a range of storages. The reservoir storage which produces a minimum value of cost plus risk is considered the optimum storage.

Main Program

A logical level flow chart for the main program is shown in Figure A-1. For each year simulated the program sets the population and daily demand, based on input data. The economic losses for the year are set to zero, and the daily cycle is begun. The supply for each day is calculated as the streamflow on that day minus that fraction of streamflow which flows into the reservoir. If the inflow to the reservoir results in a level greater than the specified storage, the overflow is added to the supply stream.

At this point, two conditions are examined. If the reservoir level is falling and only 20% of the reservoir volume remains, the money for a high capital cost alternate water source is appropriated. Water is considered to be available from the source twenty days hence. If, on the other hand, the reservoir is filling, the program checks to see if it has reached the 50% full level. If it has, all restrictions which have been imposed are lifted, and the water management subroutine is bypassed for the remainder of that year.

Now the water management subroutine is called. (See below for details of this routine). This routine simulates the actions that a local

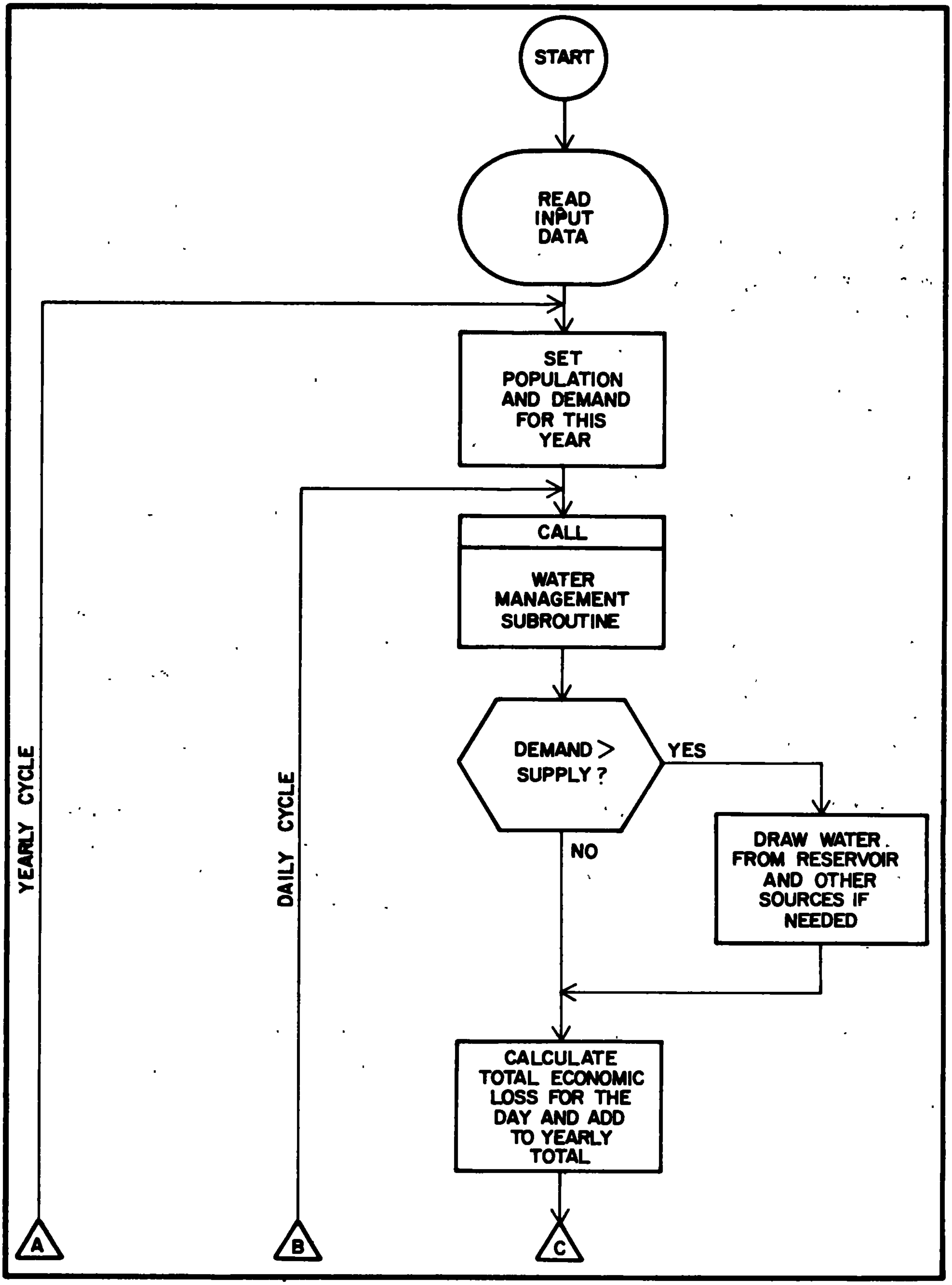


FIGURE A-1
SIMULATION MODEL MAIN PROGRAM FLOW DIAGRAM

water company might take during a water shortage period. Restrictions are imposed, based on the reservoir level for that day, thus reducing the demand for that day and causing economic losses to be incurred. These losses are calculated and added to the yearly total.

The main program now compares the supply for this day with the new, reduced demand for this day. If the demand is less than the supply, no further action is needed, and the program proceeds to the next day. If, however, the demand is greater than the supply, water is drawn from the reservoir if additional water is still needed. Now the program proceeds to the next day.

For each year being simulated, the daily cycle starts on May 1 and proceeds to December 15. If by this date the reservoir has not filled, the program continues until April 10, stopping when full capacity is reached. If the reservoir has not filled to 50% capacity by April 10, a special message is printed. Once the daily cycle for the year is completed, the program converts the total economic loss for the year into economic risk by multiplying the loss by the probability of occurrence of the streamflow level used. Five different levels of streamflow are simulated and the five risks are summed to form the total yearly risk at the particular reservoir storage specified. This risk is converted to present value, using 1970 as the base year.

The period 1970 to 2020 is simulated at five year intervals. An interpolation procedure is employed to fill in the data for the intervening years. The sum of all the risks from 1970 to 2020 is considered the total risk at the given storage level.

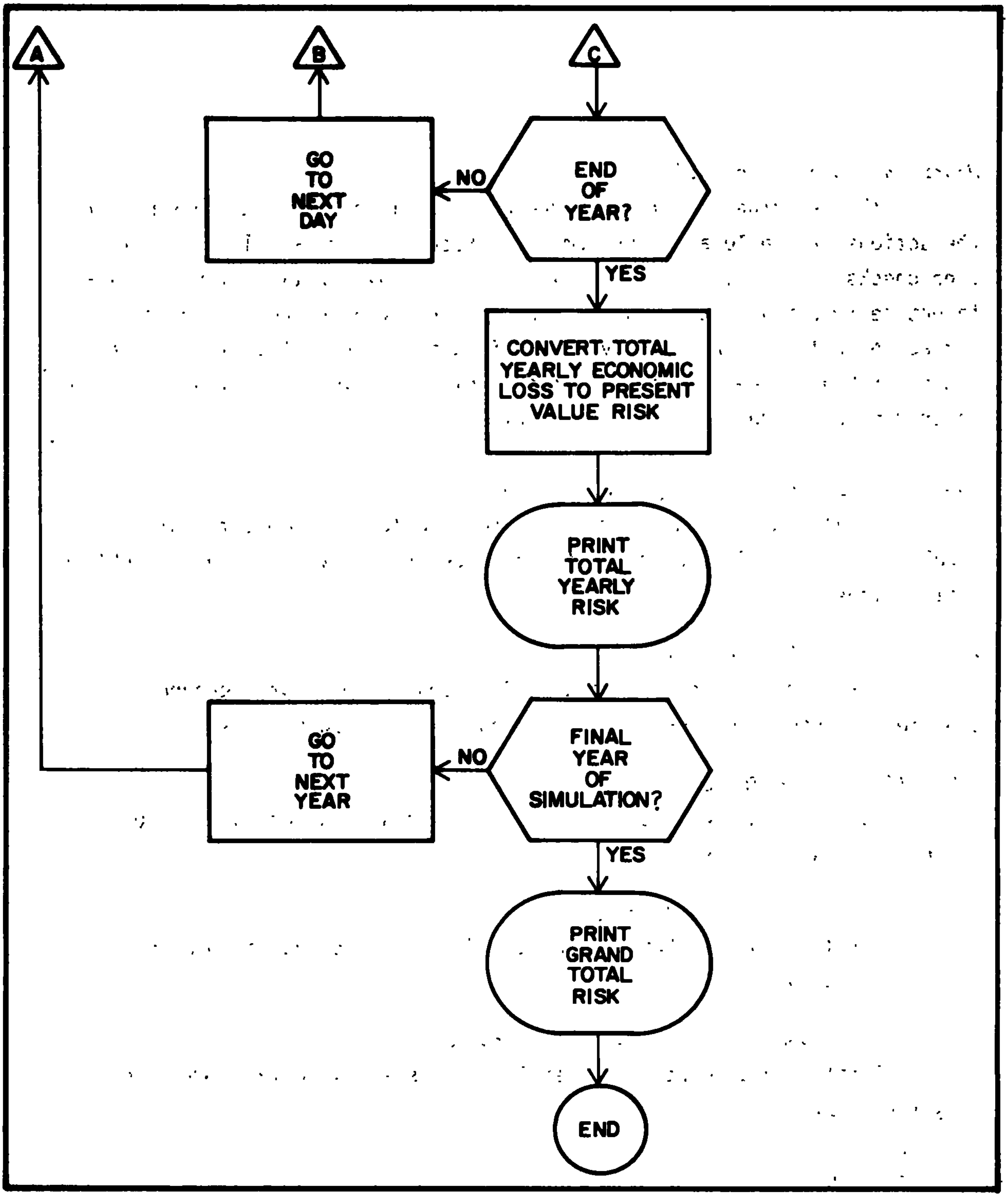


FIGURE A-1
SIMULATION MODEL
MAIN PROGRAM FLOW DIAGRAM
(CONTINUED)

Water Management Subroutine

This routine is called in the daily cycle and is used to simulate the actions of the local water company. Each time it is called, the routine checks the level of the reservoir. At certain critical levels, different restrictions are imposed, resulting in a reduced demand for that day and economic losses incurred by the different sectors. A summary of the actions taken at the critical reservoir volumes follows. A diagram of the water management routine is shown in Figure A-2.

90% Full - Invoke Voluntary Restrictions

Total demand reduced by 10%. Economic losses from external payroll, local profit plus fixed costs, external industrial revenues, and sprinkling restrictions.

70% Full - Invoke Mandatory Restrictions

Total demand reduced another 10%. Begin import of emergency water supplies. Losses from sources listed above, plus import costs.

25% Full - Reduce Industrial Operations

Total demand reduced another 15%. Losses as shown, with industrial losses increased in severity.

15% Full - Stop Industrial Operations

Total demand further reduced by 15%. Extreme losses incurred by industrial sector.

10% Full - Reduce Water Supply to Domestic Sector

Total demand reduced another 15%. Losses now include domestic consumer surplus.

Computer Code

A definition of variables is given in Figure A-3. The annotated listing is presented in Figure A-4. Sample output is given in Figure A-5.

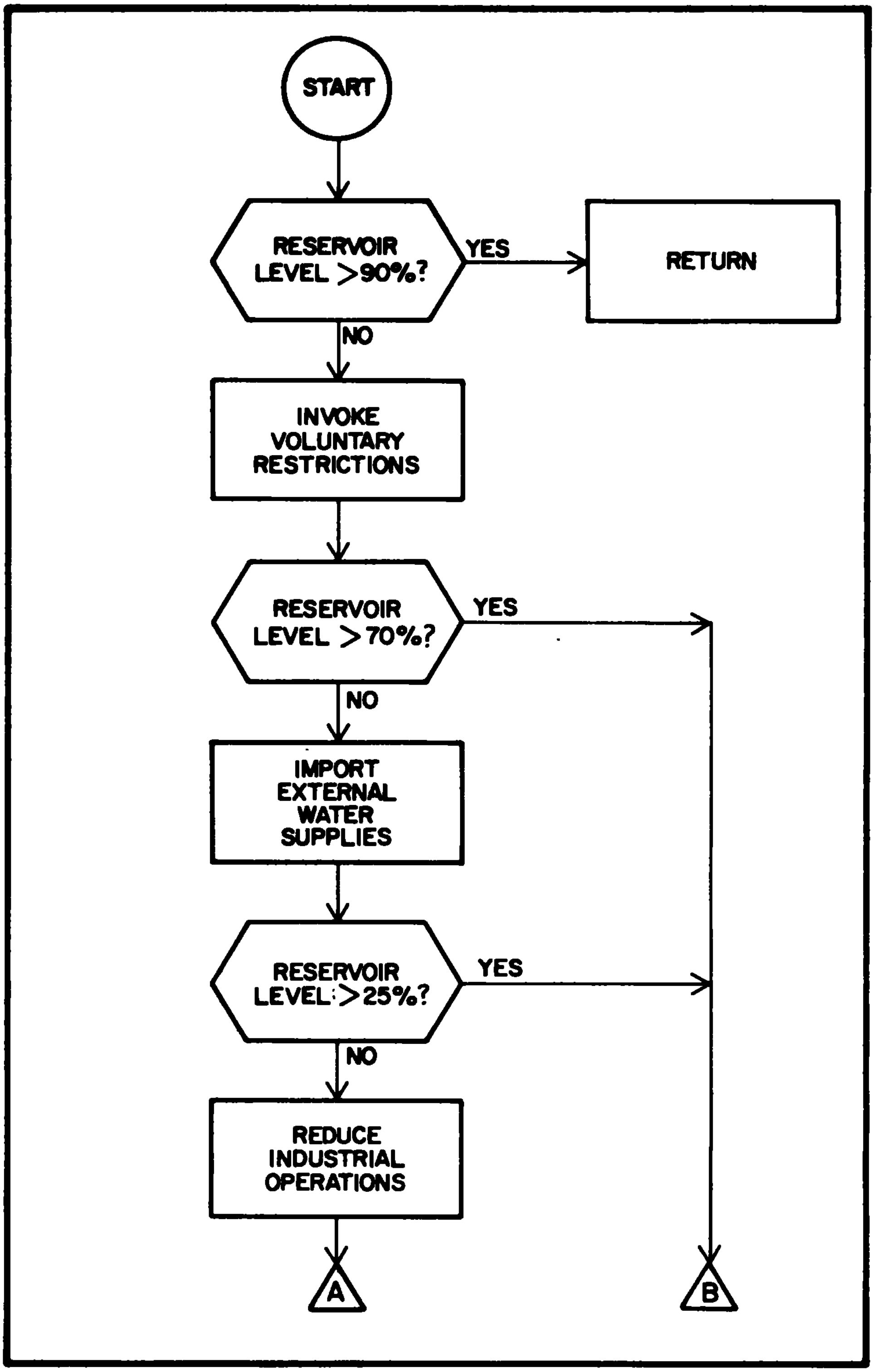


FIGURE A-2
FLOW DIAGRAM
WATER MANAGEMENT ROUTINE

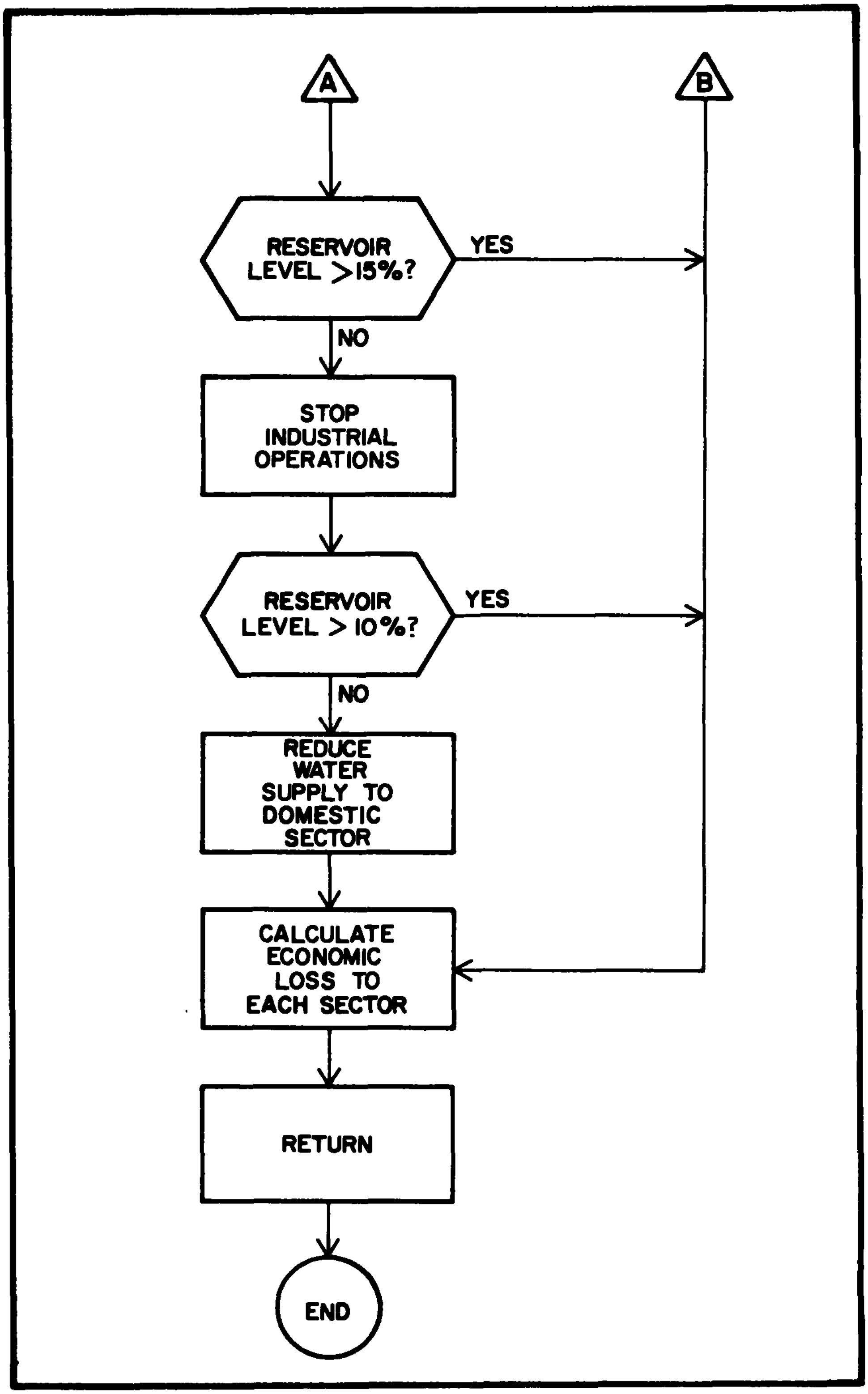


FIGURE A-2
FLOW DIAGRAM
WATER MANAGEMENT ROUTINE
(CONTINUED)

VARIABLE DEFINITIONS

Variables in Common

SUPLY (365)	Daily record of supply stream hydrology (MGD).
DMD (365)	Total daily water demand of study area (MGD).
PCT (365)	Daily record of reservoir level (= RES/CAP).
ECLOSS (8)	Economic losses incurred by the study area during water shortage (dollars). (1), (2) = import costs (3) = external payroll (4) = local profit + fixed costs (5) = high capital cost alternate source (6) = external industrial revenues (7) = sprinkling (metered + flat rate users) (8) = consumer surplus domestic (metered + flat rate users).
RES	Amount of water in the reservoir on a given day (MG)
POP	Population of study area for a given year during the simulation.

Main Program Variables

DMF (12)	Monthly demand factors
L (12)	Number of days in month (starting with May).
POPU (13)	Population of study area from 1960 to 2020 in 5 year intervals.
AVDEM (13)	Average yearly demand (MGD) of study area from 1960 to 2020 in 5 year intervals.
CFS (5)	Streamflow levels used for case study (CFS).
PROB (5)	Probability of occurrence of streamflow levels (used for converting loss to risk).
SUPPLY (365)	Daily record of supply stream hydrology (MGD) corrected for desired streamflow levels.

FIGURE A-3
GLOSSARY

YRTO (13)	Total yearly risk (dollars) from 1960 to 2020 in 5 year intervals.
YRTOT (13)	Total yearly risk (present value dollars) from 1960 to 2020 in 5 year intervals.
PERINT	Interest rate.
CAP	Reservoir storage (MG)
ALPHA	Fraction of supply stream which flows to reservoir.
PWF	Present worth factor.
<u>Water Management Subroutine Variables</u>	
IND	Daily index.
DEM	Demand on a given day (MGD).
JT	Yearly index.
FAC (10)	Economic loss rates.
AMET (13)	Number of metered customers in study area from 1960 to 2020 in 5 year intervals.
FLAT (13)	Number of flat rate customers in study area from 1960 to 2020 in 5 year intervals.
DEMIND	Industrial demand on a given day (MGD).
ALEVEL (5)	Critical reservoir levels at which restrictions are imposed.

FIGURE A-3
GLOSSARY
(CONTINUED)

```
C
C YORK MODEL
C
      COMMON/YORK/SUPLY(365),DMD(365),PCT(365)
      COMMON/ECO/ECLOSS(8),RES,POP
      DIMENSION DMF(12),L(12),SUPPLY(365)
      DIMENSION POPU(13),AVDEM(13)
      DIMENSION BETA(5),PROB(5),CFS(5)
      DIMENSION YRTOT(13),YRTO(13)
      DATA PERINT/.060/
      DATA BETA/2.88,2.25,1.60,0.96,0.80/
      DATA PROB/.1700,.2200,.2200,.0962,.0037/
      DATA CFS/90.,70.,50.,30.,25./
      DATA POPU/100.9E3,111.0E3,117.95E3,124.48E3,131.0E3,138.5E3,
     *  146.0E3,154.25E3,162.5E3,172.25E3,182.0E3,191.5E3,201.0E3/
      DATA AVDEM/14.9,16.9,20.0,21.7,23.4,25.4,27.4,30.1,32.8,35.8,
     *  38.8,42.1,45.4/
      DATA L/31,30,31,31,30,31,30,31,
     *      31,28,31,10/
      DATA CAP/250./,ALPHA/.457/
      DATA DMF/1.021,1.097,1.105,1.111,1.018,.988,.932,.967,
     *      .965,.889,.965,.936/
      CALL IFILE(20,4HJSIN)
      CALL OFILE(21,5HJSOUT)
C
C READ 1966 HYDROLOGY
C
      READ(20,100) (SUPPLY(I),I=1,345)
  100 FORMAT(12F5.1)
      MIN=131
      WRITE(21,105) CAP
  105 FORMAT('0',5X,'RESERVOIR STORAGE=',F7.1,' MG')
      RCOST=.19034*CAP*2500.+1155.*CAP
      RCOST=RCOST/1000.
      WRITE(21,106) RCOST
  106 FORMAT(6X,'RESERVOIR COST($1000)=',F11.3//)
C
C START YEARLY LOOP
C
      IYR=1965
      DO 3000 JT=3,13
      IYR=IYR+5
      WRITE(21,101) IYR
  101 FORMAT(//10X,'YEAR=',I5)
      POP=POPU(JT)
      AVDMD=AVDEM(JT)
```

FIGURE A-4
PROGRAM LISTING

```
C
C LOOP THRU THE 5 CFS VALUES
C
      YRTC(JT)=0.
      WRITE(21,102)
  102 FORMAT(/' FLOW(CFS)    RISK($1000)')
      DO 2000 JF=1,5
      ECTOT=0.
      ISUSQ=0
      LIFT=0
      IUP=0
      DO 1100 I=1,345
 1100 SUPLY(I)=BETA(JF)*SUPPLY(I)
C
C SET ECONOMIC LOSSES TO ZERO
C
      DO 110 I=1,8
  110 ECLOSS(I)=0.
      RES=CAP
C
C START DAILY CYCLE
C
      IND=0
      DO 1000 IM=1,12
      IUL=L(IM)
      DO 1000  IDAY=1,IUL
      IND=IND+1
      IF(IND.EQ.1) GO TO 185
      IF(IND.GT.229.AND.PCT(IND-1).GT.0.99) GO TO 1700
  185 DMD(IND)=AVDMD*DMF(IM)
      DEM=DMD(IND)
      SUP=SUPLY(IND)
      FACT=SUP*ALPHA
C
C PART OF CODORUS FLOW ENTERS RESERVOIR
C
      IF(SUP.GT.3.86) SUPLY(IND)=SUPLY(IND)-3.86
      IF(SUP.LE.3.86) SUPLY(IND)=0.
      RES=RES+FACT
      SUPLY(IND)=SUPLY(IND)-FACT
      IF(SUPLY(IND).LT.0.) SUPLY(IND)=0.
C
C RESERVOIR SPILLS ARE ADDED TO CODORUS
C
      IF(RES.LE.CAP) GO TO 150
      SUPLY(IND)=SUPLY(IND)+RES-CAP
      RES=CAP
  150 IF(IND.EQ.1) GO TO 200
C
C WHEN RESERVOIR DOWN TO 20%, BUILD SUSQUEHANNA PIPELINE-
C (WATER AVAILABLE AFTER 20 DAYS)
C
```

FIGURE A-4
PROGRAM LISTING
(CONTINUED)

```
      IF(ISUSQ.EQ.1.OR.PCT(IND-1).GT.0.2) GO TO 156
      ECTOT=ECTOT+650.E3*1.0
      ISUSQ=1
      IND20=IND+20
C
C IF RESERVOIR FILLING AND HAS HIT 50%, LIFT RESTRICTIONS (BYPASS
C WATER MANAGEMENT ROUTINE)
C
  156 IF(LIFT.EQ.1.OR.IND.LT.4) GO TO 200
      IF(IUP.EQ.1) GO TO 155
      IF(IND.GT.MIN.AND.PCT(IND-1).GT.PCT(IND-2)
     * .AND.PCT(IND-2).GT.PCT(IND-3)) GO TO 151
      GO TO 180
  151 IUP=1
  155 IF(PCT(IND-1).LT.0.5) GO TO 180
C     WRITE(21,152) IND
  152 FORMAT('0',10X,'LIFT=',I4)
      LIFT=1
      GO TO 200
C
C CALL WATER MANAGEMENT ROUTINE
C
  180 CALL YWATCO(IND,DEM,JT)
C
C USE SUSQUEHANNA WATER IF NEEDED AND IF AVAILABLE
C
  200 IF(ISUSQ.EQ.0) GO TO 205
      IF(IND.LT.IND20) GO TO 205
      DEF=DMD(IND)-SUPLY(IND)
      IF(DEF) 210,210,170
  170 IF(DEF-8.5) 171,175,175
  171 SUPLY(IND)=SUPLY(IND)+DEF
      ECLOSS(5)=ECLOSS(5)+DEF*32.45*1.0
      GO TO 205
  175 SUPLY(IND)=SUPLY(IND)+8.5
      ECLOSS(5)=ECLOSS(5)+8.5*32.45*1.0
C
C RESERVOIR RELEASES IF NEEDED
C
  205 DEF=DMD(IND)-SUPLY(IND)
      IF(DEF) 210,210,220
  210 PCT(IND)=RES/CAP
      GO TO 1000
  220 RES=RES-DEF
      IF(RES.LT.0.) RES=0.
      PCT(IND)=RES/CAP
 1000 CONTINUE
      IF(PCT(345).LT.0.5) WRITE(21,1710)
 1710 FORMAT(3X,'***** ALERT-RESERVOIR DID NOT REACH 50% *****')
C
C END DAILY CYCLE
```

FIGURE A-4

PROGRAM LISTING

(CONTINUED)

```
C
C ACCUMULATE LOOSSES FOR THIS CFS VALUE
C
 1700 CONTINUE
      DO 1150 I=1,8
 1150 ECTOT=ECTOT+ECLOSS(I)
C
C CONVERT LOSS TO RISK
C
      ECTOT=ECTOT*PROB(JF)
      ECT=ECTOT/1000.
      WRITE(21,103) CFS(JF),ECT
  103 FORMAT(F8.1,5X,F10.3)
C
C ACCUMULATE RISK FOR THIS YEAR
C
      YRTO(JT)=YRTO(JT)+ECTOT
 2000 CONTINUE
C
C END LOOP THRU THE 5 CFS VALUES
C
      YRT=YRTO(JT)/1000.
      WRITE(21,104) YRT
  104 FORMAT(/5X,'TOTAL YEARLY RISK($1000)=',F10.3)
C
C CONVERT RISK FOR THIS YEAR INTO PRESENT WORTH
C
      IF(JT.EQ.3) GO TO 120
      IYR1=(JT-3)*5
      PWF=1./(1.+PERINT)**IYR1
      GO TO 125
  120 PWF=1.
  125 YRTOT(JT)=YRTO(JT)*PWF
      YRT=YRTOT(JT)/1000.
      WRITE(21,126) YRT
  126 FORMAT(16X,'PRESENT VALUE=',F10.3)
 3000 CONTINUE
C
C END YEARLY LOOP
C
C
C COMPUTE TOTAL RISK (PRESENT VALUE) BY INTERPOLATION BETWEEN
C FIVE YEAR PERIODS
C
      GRTOT=0.
      DO 300 I=1,11
      YRTOT(I)=YRTOT(I+2)
      YRTO(I)=YRTO(I+2)
      GRTOT=GRTOT+YRTOT(I)
  300 CONTINUE
      DO 320 I=1,10
```

FIGURE A-4
PROGRAM LISTING
(CONTINUED)

```
      PR=0.
      DO 310 J=1,4
      PR=PR+.2
      TOT=YRTO(I)+(YRTO(I+1)-YRTO(I))*PR
      IYR1=(I-1)*5+J
      PWF=1./(1.+PERINT)**IYR1
      GRTOT=GRTOT+TOT*PWF
  310 CONTINUE
  320 CONTINUE
      GRT=GRTOT/1000.
      WRITE(21,321) GRT
  321 FORMAT(///5X,'***** TOTAL RISK($1000) AT THIS STORAGE=',F11.3)
      GRAND=RCOST+GRT
      WRITE(21,322) GRAND
  322 FORMAT(/5X,'***** COST + RISK =',F11.3)
      STOP
      END
      SUBROUTINE YWATCO(IND,DEM,JT)
C
C WATER MANAGEMENT ROUTINE
C
      COMMON/YORK/SUPLY(365),DMD(365),PCT(365)
      COMMON/ECO/ECLOSS(8),RES,POP
      DIMENSION FAC(10)
      DIMENSION AMET(13),FLAT(13)
      DIMENSION ALEVEL(5)
      DATA ALEVEL/.9,.7,.25,.15,.10/
      DATA AMET/999.,999.,9617.,11772.,13926.,16320.,
     *  18714.,21359.,24003.,27009.,30014.,33417.,36820./
      DATA FLAT/999.,999.,20703.,20506.,20309.,20112.,
     *  19914.,19717.,19520.,19323.,19126.,18929.,18731./
      NDAY=IND-1
      IF(PCT(NDAY).GT.ALEVEL(1)) RETURN
      DEMIND=.4*DEM
      EC1=0.
      EC2=0.
      DO 100 I=1,10
  100 FAC(I)=0.
C
C INVOKE VOLUNTARY RESTRICTIONS
C
      DMD(IND)=.9*DEM
      FAC(3)=0.0
      FAC(4)=0.0
      FAC(6)=.1
      FAC(7)=.01
      FAC(8)=.01
      IF(PCT(NDAY).GT.ALEVEL(2)) GO TO 500
C
C INVOKE MANDATORY RESTRICTIONS, IMPORT EMERGENCY SUPPLIES
C
```

FIGURE A-4
PROGRAM LISTING
(CONTINUED)

```
      DMD(IND)=.8*DEM
      DEF=DMD(IND)-SUPLY(IND)
      IF(DEF.LT.0.) GO TO 270
      IF(ECLOSS(1).GE.32290.) GO TO 250
C TRUCKING AND QUARRIES
      IF(DEF-2.4) 210,210,215
  210 SUPLY(IND)=SUPLY(IND)+DEF
      RES=RES+2.4-DEF
      EC1=5800.*2.4*.0827
      GO TO 270
  215 IF(DEF-3.9) 220,220,225
  220 SUPLY(IND)=SUPLY(IND)+DEF
      EC1=5800.*2.4*.0827
      EC2=580.*(DEF-2.4)*.0827
      GO TO 270
  225 SUPLY(IND)=SUPLY(IND)+3.9
      EC1=5800.*2.4*.0827
      EC2=580.*1.5*.0827
      GO TO 270
C TRUCKING STOPPED, JUST USE QUARRIES
  250 EC1=0.
      IF(DEF-1.5) 255,255,260
  255 SUPLY(IND)=SUPLY(IND)+DEF
      EC2=580.*DEF*.0827
      GO TO 270
  260 SUPLY(IND)=SUPLY(IND)+1.5
      EC2=580.*1.5*.0827
  270 FAC(3)=0.0
      FAC(4)=0.0
      FAC(6)=.2
      FAC(7)=.1182
      FAC(8)=.1182
      IF(PCT(NDAY).GT.ALEVEL(3)) GO TO 500
C
C REDUCE INDUSTRIAL OPERATIONS
C
      DMD(IND)=.65*DEM
      FAC(3)=23.09
      FAC(4)=1904.58
      FAC(6)=.5
      IF(PCT(NDAY).GT.ALEVEL(4)) GO TO 500
C
C STOP INDUSTRIAL OPERATIONS
C
      DMD(IND)=.5*DEM
      FAC(3)=66.14
      FAC(4)=9951.32
      FAC(6)=.5
      IF(PCT(NDAY).GT.ALEVEL(5)) GO TO 500
C
C REDUCE WATER SUPPLY TO DOMESTIC SECTOR
C
```

FIGURE A-4
PROGRAM LISTING
(CONTINUED)

```
      DMD(IND)=.35*DEM
      FAC(6)=1.0
      FAC(9)=.0089
      FAC(10)=.039
C
C COMPUTE ECONOMIC LOSSES FOR THIS DAY AND ADD TO YEARLY TOTAL
C
  500 ECLOSS(1)=ECLOSS(1)+EC1*1.0
      ECLOSS(2)=ECLOSS(2)+EC2*1.0
      ECLOSS(3)=ECLOSS(3)+FAC(3)/7.*.079*POP*1.0
      ECLOSS(4)=ECLOSS(4)+FAC(4)/365.*.0039*POP*1.0
      ECLOSS(6)=ECLCSS(6)+FAC(6)*DEMIND*154.5*1.0
      ECLOSS(7)=ECLOSS(7)+FAC(7)*AMET(JT)*1.0+FAC(8)*FLAT(JT)*1.0
      ECLOSS(8)=ECLOSS(8)+FAC(9)*AMET(JT)*1.0+FAC(10)*FLAT(JT)*1.0
      RETURN
      END
```

FIGURE A-4
PROGRAM LISTING
(CONTINUED)

```
RESERVOIR STORAGE=   500.0 MG
RESERVOIR COST($1000)=      815.425



         YEAR= 1970

FLOW(CFS)       RISK($1000)
   90.0            10.702
   70.0            45.769
   50.0           610.196
   30.0           529.202
   25.0            23.432

     TOTAL YEARLY RISK($1000)=   1219.302
                PRESENT VALUE=   1219.302


         YEAR= 1975

FLOW(CFS)       RISK($1000)
   90.0            18.309
   70.0            82.347
   50.0           796.940
   30.0           632.044
   25.0            27.330

     TOTAL YEARLY RISK($1000)=   1556.969
                PRESENT VALUE=   1163.458
```

FIGURE A-5
SAMPLE OUTPUT

```
          YEAR= 1980

FLOW(CFS)     RISK($1000)
   90.0          27.608
   70.0         345.584
   50.0         988.325
   30.0         727.074
   25.0          30.821

     TOTAL YEARLY RISK($1000)=   2119.412
                PRESENT VALUE=   1183.469


          YEAR= 1985

FLOW(CFS)     RISK($1000)
   90.0          40.725
   70.0         599.414
   50.0        1306.520
   30.0         818.277
   25.0          34.099

     TOTAL YEARLY RISK($1000)=   2799.035
                PRESENT VALUE=   1167.940


          YEAR= 1990

FLOW(CFS)     RISK($1000)
   90.0         206.530
   70.0         841.675
   50.0        1500.630
   30.0         914.905
   25.0          38.139

     TOTAL YEARLY RISK($1000)=   3501.877
                PRESENT VALUE=   1091.902
```

FIGURE A-5
SAMPLE OUTPUT
(CONTINUED)

```
          YEAR=  1995

FLOW(CFS)      RISK($1000)
   90.0          425.786
   70.0         1158.653
   50.0         1760.349
   30.0         1011.103
   25.0           42.507

    TOTAL YEARLY RISK($1000)=   4398.399
                 PRESENT VALUE=   1024.821


          YEAR=  2000

FLOW(CFS)      RISK($1000)
   90.0          655.235
   70.0         1410.813
   50.0         1957.988
   30.0         1136.885
   25.0           50.564

    TOTAL YEARLY RISK($1000)=   5211.484
                 PRESENT VALUE=    907.372


          YEAR=  2005

FLOW(CFS)      RISK($1000)
   90.0          901.637
   70.0         1732.882
   50.0         2238.794
   30.0         1319.922
   25.0           60.197

    TOTAL YEARLY RISK($1000)=   6253.433
                 PRESENT VALUE=    813.604
```

FIGURE A-5
SAMPLE OUTPUT
(CONTINUED)

```
          YEAR= 2010

FLOW(CFS)     RISK($1000)
   90.0         1119.695
   70.0         1979.158
   50.0         2538.134
   30.0         1539.537
   25.0           68.359

    TOTAL YEARLY RISK($1000)=  7244.883
               PRESENT VALUE=   704.363


          YEAR= 2015

FLOW(CFS)     RISK($1000)
   90.0         1429.311
   70.0         2262.727
   50.0         2865.055
   30.0         1766.105
   25.0           80.519

    TOTAL YEARLY RISK($1000)=  8403.717
               PRESENT VALUE=   610.531


          YEAR= 2020

FLOW(CFS)     RISK($1000)
   90.0         1628.903
   70.0         2618.694
   50.0         3118.699
   30.0         2008.699
   25.0           92.109

    TOTAL YEARLY RISK($1000)=  9467.103
               PRESENT VALUE=   513.954


    ***** TOTAL RISK($1000) AT THIS STORAGE=   48696.563

    ***** COST + RISK =   49511.988
```

FIGURE A-5
SAMPLE OUTPUT
(CONTINUED)

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13. ABSTRACT

This report develops a procedure for estimating income losses, to a defined region, associated with varying degrees of water shortage resulting in a frequency-loss function. An empirical list of the procedure was developed for the York, Pennsylvania Water Service Area, which experienced a substantial water shortage in 1966. Study of community response to actual or potential drouth reveals a number of different perspectives - the water manager, residential, commercial and industrial users and government. This study opens the way to an alternative method of assessing the benefits for adequate municipal water supplies; it distinguishes between short-run and long-run plans; and the role which each plays in resource planning.

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