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SUSITNA HYDROELECTRIC PROJECT

TASK 11

TASK 11.03
CLOSE-OUT REPORT
SUSITNA RISK ANALYSIS
APRIL 1982

Prepared by:
ACRES

ALASKA POWER AUTHORITY

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TABLE OF CONTENTS

Table of Contents (Cont'd)

LIST OF TABLES

LIST OF FIGURES

1 - INTRODUCTION

1 - INTRODUCTION

1.1 - Background

Acres American Incorporated (Acres) entered into an agreement with the Alaska Power Authority in December, 1979, to conduct a detailed feasibility study and prepare a license application for the Susitna Hydroelectric Project. The work undertaken by Acres is in accordance with a detailed plan of study (POS) which was originally published in February, 1980, and which has been subsequently updated from time to time in response to public comments and legislated requirements, and to account for the implications of the results of major investigation programs.

A rigorous development selection process took into account multiple criteria and a broad range of potential development schemes. It resulted in the choice of a two-dam system on the Susitna River as the apparent best method for meeting a portion of future energy requirements in the Southcentral Railbelt in Alaska. The first draft of the detailed feasibility study was submitted to the Alaska Power Authority in February, 1982, and that report provides complete descriptions of the proposed project, as well as an assessment of major issues which are likely to determine the acceptability of the project.

1.2 - Purpose

This report provides the details of the methodology, evaluation, analysis, and assessment of the risks associated with (1) the construction capital costs and schedule of the Watana and Devil Canyon site developments, and (2) the operational outages of the Susitna transmission system.

The purpose of this risk analysis is to identify all relevant risks which, if realized, could impact cost, schedule, project safety, and public confidence; to determine probable consequences of realizing risks; to assess relevant preventive measures and responses; to estimate the probability that project criteria will be satisfied; and to stimulate documentation of problems and solutions to improve expected risk performance. This risk analysis was conducted by an independent team of senior engineers of various disciplines who provided an objective assessment of the project design, cost estimate and construction schedule. Frequent communication was made with the project groups to assure consistency and reasonableness of the underlying assumptions criteria and methodology.

1.3 - Report Structure

The sections of the report that follow have been organized to allow the reader to systematically progress through the details and results of the analysis. These sections are:

(a) Section 2 provides a summary of the report and the analysis and highlights the major conclusions.

(b) Section 3 presents the methodology that was employed in the technical evaluation and the subsequent analysis and assessment.

(c) Section 4 presents the basis of the technical evaluation of the risks on which the formal computer-aided risk analysis was done.

(d) Section 5 documents the methodology and calculation process of the computer-aided risk analysis.

(e) Section 6 presents and interprets the results of this risk analysis.

2 - SUMMARY AND CONCLUSIONS

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Economic analyses accomplished as a part of Task 6 indicate that the Susitna Hydroelectric Project is viable in economic terms through a broad range of possible deviations from expected values of key parameters. Even so, net project benefits are sensitive to Susitna capital cost variations; and alternative financing plans are predicated on the assumption that the proposed project schedule will be met. Every reasonable effort was made to prepare conservative cost estimates and to produce an achievable schedule. Yet, uncertainties are involved and their potential importance demands that they be given appropriate consideration at various stages in project development.

A risk analysis was undertaken as the basis for determining the extent to which perceived risks are likely to influence capital costs and schedule. In addition, because a mature Susitna Project would represent a major portion of the total generation system, a further risk analysis was accomplished to assess the probability and consequences of a long-term outage of the proposed transmission system. This section summarizes the risk analyses.

2.1 - The Approach

Any major construction effort is inevitably exposed to a large number of risks. Floods may occur at crucial times. Accidents shouldn't happen, but they sometimes do. Subsurface investigations, no matter how thorough, don't always tell the whole story about what will be found when major excavation work goes on. The normal estimation process implicitly accounts for a set of reasonably "normal" expectations as direct costs are developed, adding a contingency to the directly computed total on the grounds that problems usually do occur even though their specific nature may not be accurately foreseen at the outset.

The Susitna risk analysis took explicit account of 21 different risks, applying them as appropriate to each major construction activity. The effort involved combining reasonably precise data (e.g., the probability that a particular flood crest will occur in any given year can be determined from analysis of hydrologic records) with numerous subjective judgements (e.g., until a particular flood crest does occur, we cannot know with any degree of certainty what havoc it will wreak). The overall methodology is illustrated on Figure 2.1 and is briefly described below:

(i) The base cost and schedule estimation effort was reviewed to determine important underlying assumptions, areas of uncertainty, proposed construction methods and sequence.

(ii) A risk list was developed, providing an initial statement of major areas of uncertainty to be considered in the analysis.

It was important at this stage to begin to make initial gross assessments of how each risk might affect the project at various stages of completion, as well as to estimate the extent to which dependency existed between one risk and another. In this regard, for example, the risk of a major flood is independent of the risk that geologic conditions will differ from those expected. On the other hand, it can be reasonably asserted that the risk that any given contractor will experience a construction accident is at least partially dependent on the risk that the same contractor will have poor construction quality control.

(iii) Upon completion of the estimate review and concurrent with development of an initial risk list, a review was made of proprietary risk analysis software as the basis for specifying particular modifications which would permit proper treatment of all data elements.

(iv) A data collection effort was accomplished for each identified risk and a determination was made of the probability that each of a selected range of risk magnitudes would be realized in any given year. Where data gaps existed, a decision analysis process was used to produce required information.

(v) Transformation criteria were developed so that individual risk analysts could more easily view the consequences of realizing any single risk in terms of "natural" criteria. For example, it is easier to think in terms of the volume of earth involved in a slope failure than to think directly of its cost impact. Transformation criteria can then be used to convert to cost and schedule implications.

(vi) Software revisions were made in accordance with specifications noted at subparagraph (iii) above concurrent with the analysis of risks.

(vii) For each major construction activity at each dam site, the consequences of realizing each possible risk magnitude were assessed and estimated. Responses (actions which will be taken if a particular consequence is realized) were developed.

(viii) As the work proceeded, reviews and revisions were made to introduce collective judgements from diverse disciplines into the process.

(ix) The initial data set was run and interpreted. Anomalies were identified and risks emerging as most significant were further reviewed to ensure that their consequences had been adequately accounted for.

(x) Whereas the primary risk analysis effort focused upon the construction phase, a separate analysis of the transmission system was also made to assess the likelihood and the consequences of a major transmission outage. A similar methodology was followed in this sub-analysis.

(xi) All input data was updated based on the results of step (ix) above.

(xii) A final run was made to compute expected values of costs and completion schedules as well as to create probability distributions for these items. This final output provided the basis for interpretation. Similiarly a run was made to compute expected values for transmission system loss.

2.2 - Elements of the Analysis

Figure 2.2 graphically depicts important questions which were addressed at the start and relates them to elements of the analysis. Each element is further subdivided as follows:

(a) Configurations. Three primary configurations were considered:

- The Watana hydroelectric project (with transmission)
- The Devil Canyon hydroelectric project (with transmission)
- The Susitna transmission system alone.

Separate risk studies of these configurations permitted the production of data which can be aggregated in various ways to accommodate alternative "power-on-line" dates which differ according to the various demand forecasts.

(b) Configuration States. Two configuration states were considered:

- Construction Period--applicable to Watana and Devil Canyon.
- Operation Period--applied only to the Susitna transmission system configuration.

(c) Risks. Twenty-one risks were identified for consideration in the construction analysis and were grouped as follows: Additionally many of these risks also applied in the operational risk analysis.

- Natural Risks

  - Flood
  - Ice
  - Wind
  - Seismic
  - Permafrost deterioration
  - Geologic Conditions
  - Low streamflow

- Design Controlled Risks

  - Seepage/piping erosion
  - Ground water

- <u>Construction Risks</u>

  - Equipment availability
  - Labor strikes/disputes
  - Material availability
  - Equipment breakdown
  - Material deliveries
  - Weather

- <u>Human Risks</u>

  - Contractor capability
  - Construction quality control
  - Accidents
  - Sabotage/Vandalism

- <u>Special Risks</u>

  - Regulatory delay
  - Estimating variance

(d) <u>Activities</u>. For each configuration state involving construction, up to 22 activities were considered. For Watana, for example, these included:

- Main Access
- Site Facilities
- Diversion Tunnels
- Cofferdams
- Main dam excavation
- Main dam fill initial portion
- Main dam fill final portion
- Relict channel protection
- Chute spillway
- Emergency spillway
- Service spillway tunnels
- Intake
- Penstock
- Powerhouse
- Transformer gallery
- Tailrace and surge chambers
- Turbine-generators
- Mechanical/electrical equipment
- Switchyard
- Transmission
- Impoundment
- Test and commission

(e) <u>"Damage" Scenarios</u>. Up to 10 different "damage" or "impact" scenarios were associated with each logical risk-activity combination. While these varied significantly from one risk-activity combination to another, they generally described a range of possibilities which accounted for discrete increments extending from "no damage" to "catastrophic loss."

(f) Criteria. The consequences of realizing particular risk magnitudes for each activity were measured in terms of the following construction criteria:

- Cost implications
- Schedule implications
- Manpower requirements

Operational criteria were defined as days of power lost in the Anchorage and Fairbanks load centers.

(g) Boundary Conditions. The following assumptions and limitations were established to permit a reasonable and consistent analysis of the problem:

- All cost estimates were made in terms of January 1982 dollars. Thus, results are presented in this report in terms only of real potential cost variations, exclusive of inflation.

- The analysis was limited only to the construction periods for Watana and Devil Canyon since the greatest potential cost and schedule variance would be possible during these periods. The risk analysis for the operating period was associated solely with the transmission system since that configuration represents the most likely source of a major system outage during project operation.

- The risk analysis was accomplished concurrently with finalization of the total project cost estimate and was necessarily associated with the feasibility level design. There is clearly some potential for design change as the project proceeds and a future risk analysis should be undertaken coincident with completion of final detailed design and prior to commitment to major construction activities. Even so, the "estimating variance" risk takes into account the fact that some design changes are likely to appear as detailed design effort proceeds.

- A great deal of subjective judgement was necessarily involved in assessing certain probabilities and in predicting possible damage scenarios. This effort was accomplished initially by individual qualified professionals in the various disciplines and was subjected to iterative group review and feedback efforts. To the extent that individual biases entered the analysis, their effects were probably mutually offsetting. Even so, sensitivity tests were made for risks which were important contributors to the final results.

- The risk list does not include the important possibility of funding delays or of financing problems. These issues were dealt with in a separate financial risk analysis.

2.3 - Risk Assessments

For each of the risks identified in paragraph 2.2 (c) above, the assessment commenced with detailed definition of credible events. Whereas flood was identified as a risk, for example, we sought to define the magnitudes of floods which could occur and to associate with each magnitude the probability that it would occur. Depending upon the particular risk under consideration, data sources included reasonably accurate scientific data (particularly applicable to the natural risk category), historical experience on water resources projects, and, where data gaps existed, subjective group judgements.

In each case, we sought first to identify some maximum credible event. (What is the most extreme event, albeit highly unlikely, that could occur?) This choice set an upper limit on a scale of possible events which always began with a minimum magnitude corresponding to a "no damage" situation. Continuing with flood as an example, the maximum credible event was considered to be the probable maximum flood which had been computed in the hydrologic studies (corresponding to a return period of more than 10,000 years and an annual probability of occurrence of less than .0001). The minimum magnitude "no damage" event at the lower end of the scale varied from activity to activity. (In this regard, for example, a cofferdam built early in the construction period and designed to withstand a 50 year flood event can be expected to suffer damage if a 100 year event actually occurs. Late in the project, a 100 year event would not only cause no damage to structures in place, but also it might be regarded as fortuitous because it could improve the reservoir impoundment schedule.)

Once risks were defined and logical risk-activity combinations were reviewed, we had to conceptualize the consequences of realizing each selected risk magnitude. (If this risk magnitude is realized, will a partially completed structure be damaged? Will it fail? If it fails, is some other work in progress disrupted?) Clearly, one cannot know with certainty what precise damage scenario should be associated with a given risk magnitude for a particular activity. Thus, we defined a range of damage scenarios and associated with each of them a probability of occurrence if a particular risk magnitude is realized.

Even if a particular risk level is realized <u>and</u> a particular damage scenario is suffered, we still cannot be certain as to the cost of restoring the activity nor can we be sure how long it will take to do so. Things do go exceedingly well every once in a while. Occasionally they go very badly indeed. Each of the risk analysts was asked to provide three values for each criterion:

- A minimum corresponding to the one time in twenty that the weather is particularly good, materials are readily available, no accidents occur, and the like.

- A modal value associated with the most likely expectation of the analyst.

- A maximum value corresponding to the one time in twenty that everything is more difficult than expected.

In the computerized calculation process, the three criteria values supplied by the risk analyst were fitted to a triangular distribution, which approximated the Beta distribution illustrated at the bottom of Figure 2.3.

In effect, then, designation of the three conceptual criteria values led to generation of a histogram with relatively narrow intervals and a nearly continuous range of possible values over a relatively wide spectrum.

Figure 2.3 illustrates the structural relationship for handling risk-activity combinations, damage scenarios, and criteria values.

While the procedure described above is generally applicable, some commentary on particular aspects of its application and on certain unique risks is appropriate:

(a) The terminology "damage" scenario has been used for convenience since most identified risks will normally be thought of as reasons that the cost will be higher than had been estimated or that the schedule will be exceeded. In fact, however, the process does permit consideration of what might be regarded as a negative "damage" scenario. The geologic conditions risk is an excellent example. The cost estimate was produced on the basis of estimates of requirements for some concrete lining in the penstocks, extensive grouting, a certain level of rock bolting, and the like. If geologic conditions are found to be better than currently assumed, the costs could be less and the schedule might be accelerated.

(b) The estimating variance risk was treated in a special way because it cannot easily be conceptualized in physical terms. It accounts for inevitable differences which do occur between estimates and actual bids, and between bids and actual activity costs--even in the absence of any other identified risks. Its probability of occurrence and associated range (fractions or multiples of the basic estimate) were determined from historical data on water resources projects. It includes, but is not necessarily limited to, such considerations as:

- The influence of competition and market pressures;
- Estimating discrepancies or errors in unit quantities on the part of both owner's estimator and bidder;
- Particular contract forms and the owner's acceptance/nonacceptance of certain risks;
- Labor market conditions and the nature of project labor agreements;
- Productivity and efficiency changes over time;
- The cost implications of variances between activity schedules and actual activity durations;
- The potential for scope changes over time;
- Extraordinary escalation of construction costs above the underlying inflation rate.

(c) In addition to estimating variance, a second special risk is associated with regulatory matters. Various legislated controls will most certainly be applied to the Susitna Project, and it is a relatively simple matter to compute the minimum time in which regulatory requirements could be satisfied. It is a far more difficult task to estimate the precise nature and duration of possible future regulatory delays. It would also clearly be inappropriate to attempt to apply regulatory risks at the activity level.

This risk was handled by developing a separate distribution for a range of periods necessary for satisfaction of important licensing and permitting requirements.

Data used in arriving at a distribution were based on recent experiences on other water resources projects as well as on discussions with staff members of the Federal Energy Regulatory Commission. The effect of applying the regulatory risk is primarily one of shifting the starting time for commencement of construction activities, leading to corresponding change in the projected completion time. A lesser effect of the regulatory risk was to introduce delays during construction.

Regulatory requirements have been an important influence during the past decade on major construction costs and schedules, though it is difficult to isolate their effects. In order to separately consider estimating variance risks and regulatory risks, "estimating variance" probability determination relied heavily upon water resources construction data developed for projects essentially completed prior to the passage of the National Environmental Policy Act (NEPA). As noted above, regulatory risk probability distributions were derived from more recent projects.

(d) Each of the various construction risk magnitude probabilities was originally calculated as an annual value. On a risk-activity by risk-activity basis, these annual values were then converted by standard computational procedures to provide a probability of occurrence during the duration of the activity.

(e) The concept of "response" is particularly important in the formal risk analysis process. As the terminology suggests, a "response" represents the action to be taken _if_ a particular event occurs. There are two kinds of "response." The _first_--and most often used--is an expected reaction to the occurrence of a particular damage level. (I.e., _if_ this damage level is incurred, _then_ what actions must be taken to restore the activity to its pre-damage status? _And_ what cost, schedule, and manpower implications [consequences] _will_ result?) A second kind of response can also be considered and it provides an important link between the design team and the risk analysis team. This latter type is the "preventive response." (I.e., what changes might reasonably be made in the design and/or construction procedures which would permit us to avoid or reduce a particular damage level? Is the cost and schedule change which might ensue worthwhile when compared to the probability and magnitude of the consequences which would otherwise be incurred?) Several preventive responses were identified by risk analysts during the risk study and several of these were incorporated into the project design and design criteria. There may be further opportunities for preventive response. Since none would be chosen unless it offered a net benefit to cost and/or schedule, it may reasonably be concluded that, as detailed design proceeds and as subsequent risk analysis updates are accomplished, a gradual reduction in the spread of possible values can be expected.

2.4 - Interpretation of Results

(a) Presentation of Data. A variety of formats is available for presentation of risk analysis results. Figure 2.4 illustrates three common methods. The choice of a particular graphic display and of "expected value" calculations is explained as follows:

- The density form ([2] on Figure 2.4) plots the probability that a particular value will occur against its value. This kind of distribution was used in the preparation of histograms for risks and damage levels, as may be seen on Figure 2.3. Insofar as presentation and interpretation of final outputs are concerned, however, the density form is not as meaningful. The decision makers tend to be more concerned about the confidence they can have that a particular value will not be exceeded than that the same value will actually be achieved. (In other words, it is more meaningful to know that there is a 90 percent chance that a certain cost will be $100 million or less than it is to know that there is a 5 percent chance that the cost will be between $95 and $100 million.)

- The reverse cumulative form ([3] on Figure 2.4) provides a measure of the probability that a particular criterion value will be exceeded. (E.g., such a distribution might indicate that there is a 10 percent chance that a particular activity will cost more than $100 million.)

- The cumulative form ([1] on Figure 2.4) provides a measure of the probability that a particular value will not be exceeded. This latter form was selected for presentation of results since it relates directly to the decision maker's need to know how confident he can be that total costs will be within certain limits and also allows him to understand that further exposure may exist.

- The "expected value" is the value which would appear on the average if a large number of projects of this type were constructed independently under the same conditions.

Minor variations in activity costs were generated by the estimating team concurrent with development of the risk analysis. In addition, account was taken of the expectation that construction costs will escalate at a faster rate than normal inflation--both in the economic analyses and the risk analyses. To avoid confusion regarding absolute cost values, the results of the risk analysis are presented in this section as percentages of the esimated project cost or as ratios between actual costs and estimated costs.

(b) Cost Distribution

Figure 2.5 presents the cumulative probability distribution for the total Susitna project during construction. The figure may be interpreted as follows:

(i) The expected value of the final project cost in January 1982 dollars is 90.6 percent of the project estimate.

(ii) There is a 73 percent probability that the final project cost will not exceed the project estimate.

(iii) There is a 47 percent probability that the final project cost will not exceed the "low" value tested in the economic analysis (Point "B"), and a 90 percent probability that the "high" value (Point "C") will not be exceeded.

(iv) There is a small but finite chance that the final project cost will be as much as 140 percent of the project estimate.

(c) Schedule Variations

Figure 2.6 provides an indication of the schedule risks for the Watana project as a whole. There is a 65 percent probability that the project will be completed on schedule and nearly a 40 percent probability that it will be completed a year early. Significant delays, largely introduced by regulatory risks, are possible; and, there is about a 2 percent chance that the project will be delayed as much as 40 months. Excluding regulatory risks, whose primary effect is on the starting date for construction, our analysis indicates that there is about a 2 percent chance that the project will take 15 months longer than the estimated eight-year period between commencement and completion.

(d) Transmission Outages

Because the Susitna project would represent a large portion of the total generating system in the Railbelt, it is important to consider the vulnerability of the transmission system. The most critical period falls in the first decade of the 21st century. After that time, it may reasonably be argued that additional generating resources will be brought on line, gradually reducing the percentage of total energy provided by the Susitna project. After an initial shakedown period, the transmission system will have matured to some relatively steady state; and, because of built-in redundancies, it will not, under normal circumstances, lead to loss of energy delivery capability to major load centers. Extreme risks (major floods, unusually high wind, etc.) will continue to be possible, however. The results of our analysis of an assumed mature transmission system suggest that the expected values of losses in energy delivery capability are less than one day in ten years from both Anchorage and Fairbanks.

2.5 - Conclusions

Based upon the risk analysis, it is concluded that:

(i) The probabilities that actual costs will not exceed values subjected to sensitivity tests in the economic analysis are as follows:

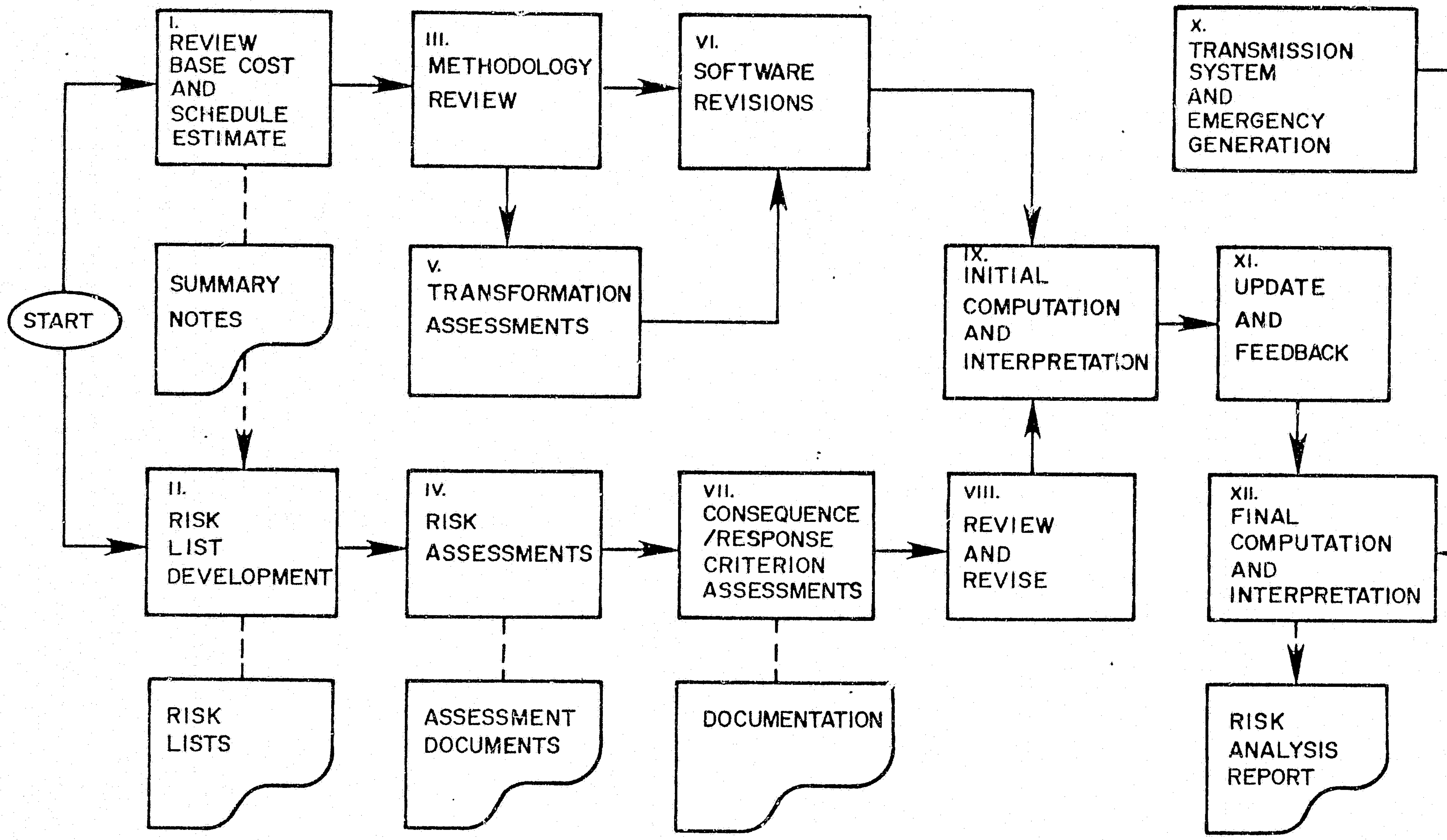
Value	Probability that value will not be exceeded
Project estimate	73 percent
Low capital cost tested in the economic analysis	47 percent
High capital cost tested in the economic analysis	90 percent

(ii) Exposure to potential costs above the project estimate does exist and there is about a 1 percent chance that an overrun of 40 percent or more (in 1982 dollars) will occur.

(iii) The annual probability that no interruption in energy delivery to major load centers will occur as a result of transmission line failures is in excess of 95 percent.

Expected values of energy delivery interruptions are less than one day in ten years and are consistent with loss of load probabilities assumed in the generation planning efforts.

(iv) There is a 65 percent probability that the Watana project will be completed prior to the scheduled time in 1993. Exposure to schedule delays is heavily influenced by regulatory requirements and there is a 10 percent probability that the Watana project will not be completed until 1995 or later.



RISK ANALYSIS STUDY METHODOLOGY

FIGURE 2.1

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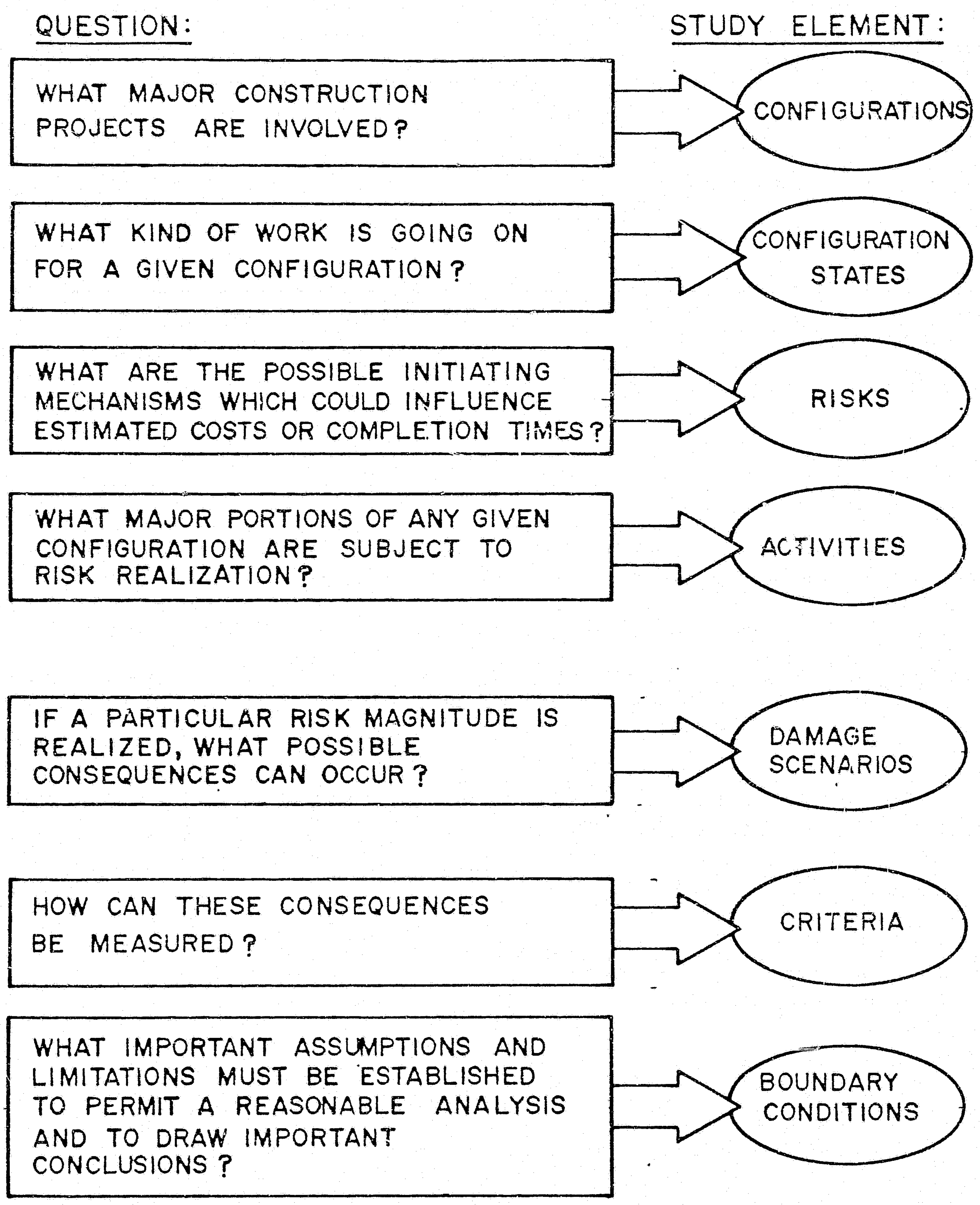
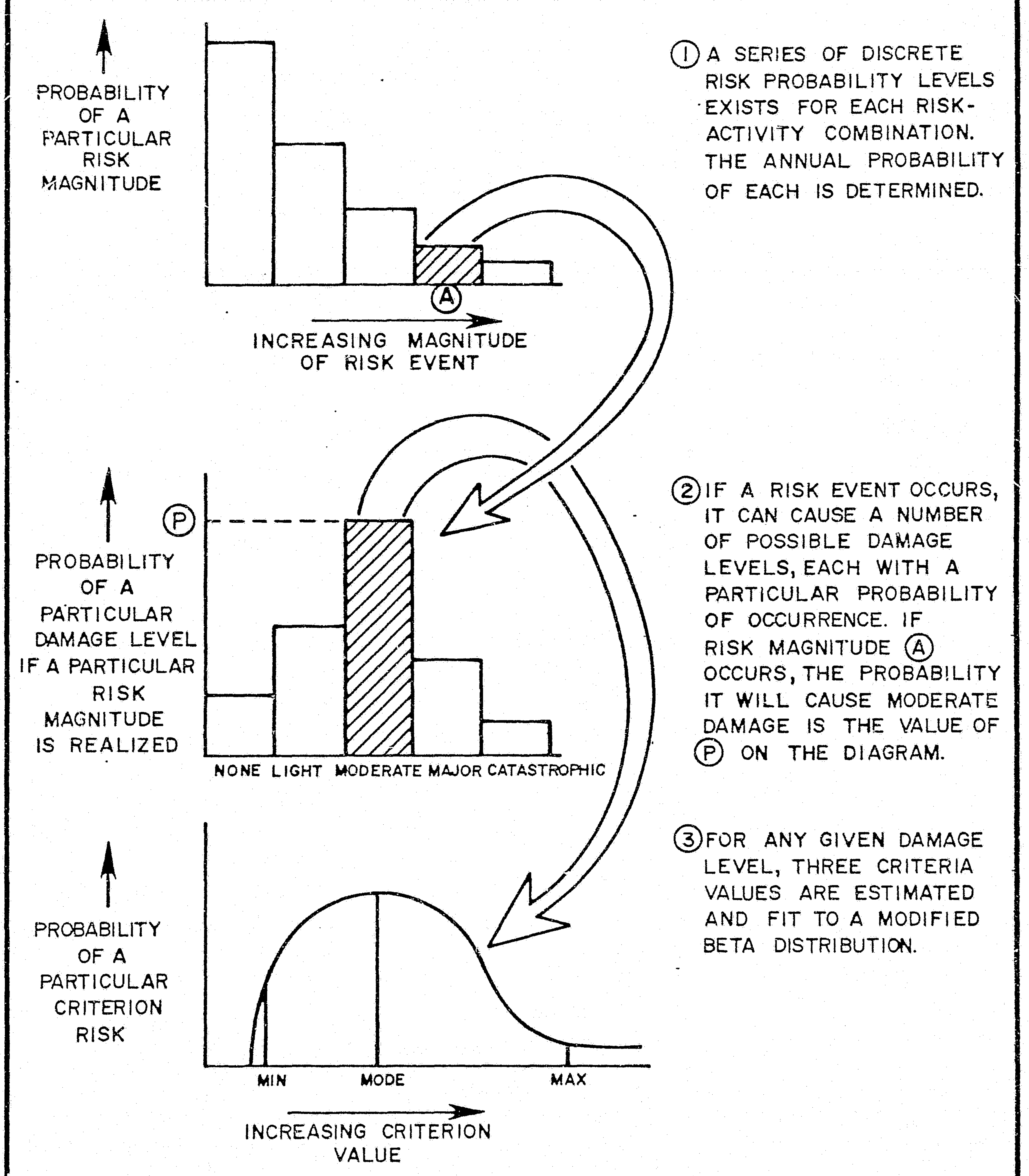


ELEMENTS OF THE RISK ANALYSIS

FIGURE 2.2



STRUCTURAL RELATIONSHIP FOR HANDLING RISK-ACTIVITY COMBINATIONS, DAMAGE SCENARIOS AND CRITERIA VALUES

FIGURE 2.3

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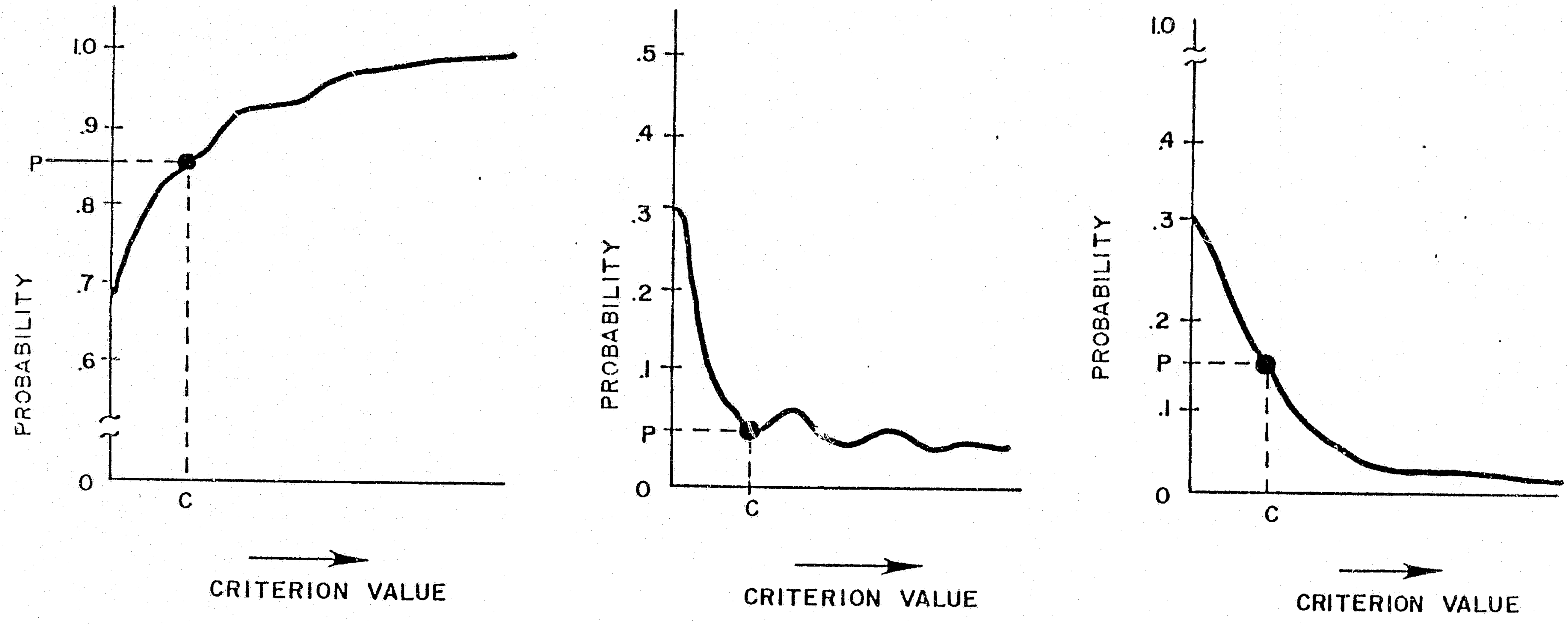

① CUMULATIVE DISTRIBUTION

ANY POINT ON THE CURVE INDICATES THE PROBABILITY (P) THAT THE CRITERION VALUE (C) WILL NOT BE EXCEEDED.

② DENSITY FORM

ANY POINT ON THE CURVE INDICATES THE PROBABILITY (P) THAT A PARTICULAR CRITERION VALUE (C) WILL BE INCURRED.

③ REVERSE CUMULATIVE

ANY POINT ON THE CURVE INDICATES THE PROBABILITY (P) THAT THE CRITERION VALUE (C) WILL BE EXCEEDED.

ALTERNATIVE FORMATS FOR PRESENTING THE ANALYTICAL RESULTS

FIGURE 2.4

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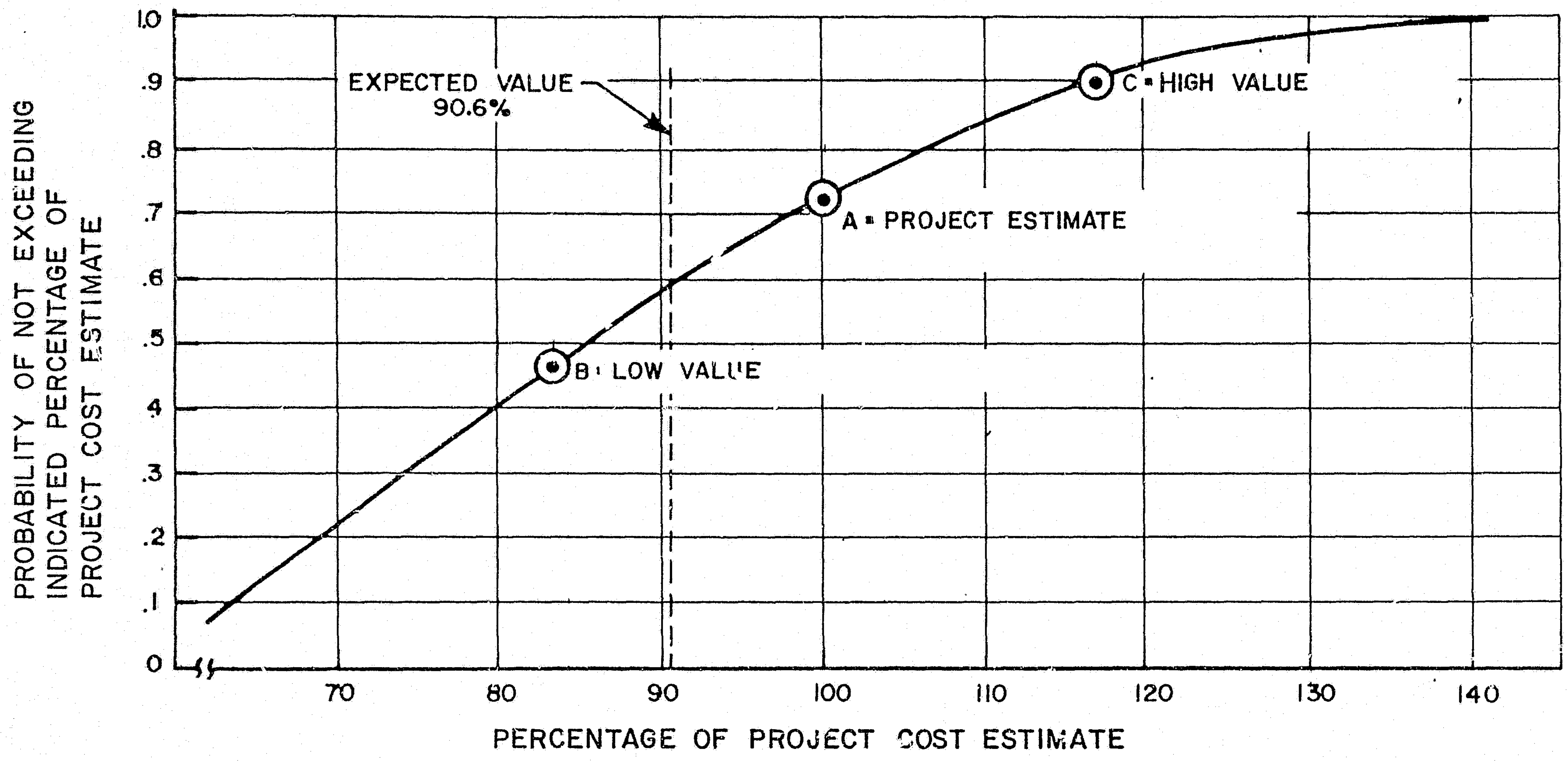

CUMULATIVE PROBABILITY DISTRIBUTION FOR SUSITNA HYDROELECTRIC PROJECT

FIGURE 2.5

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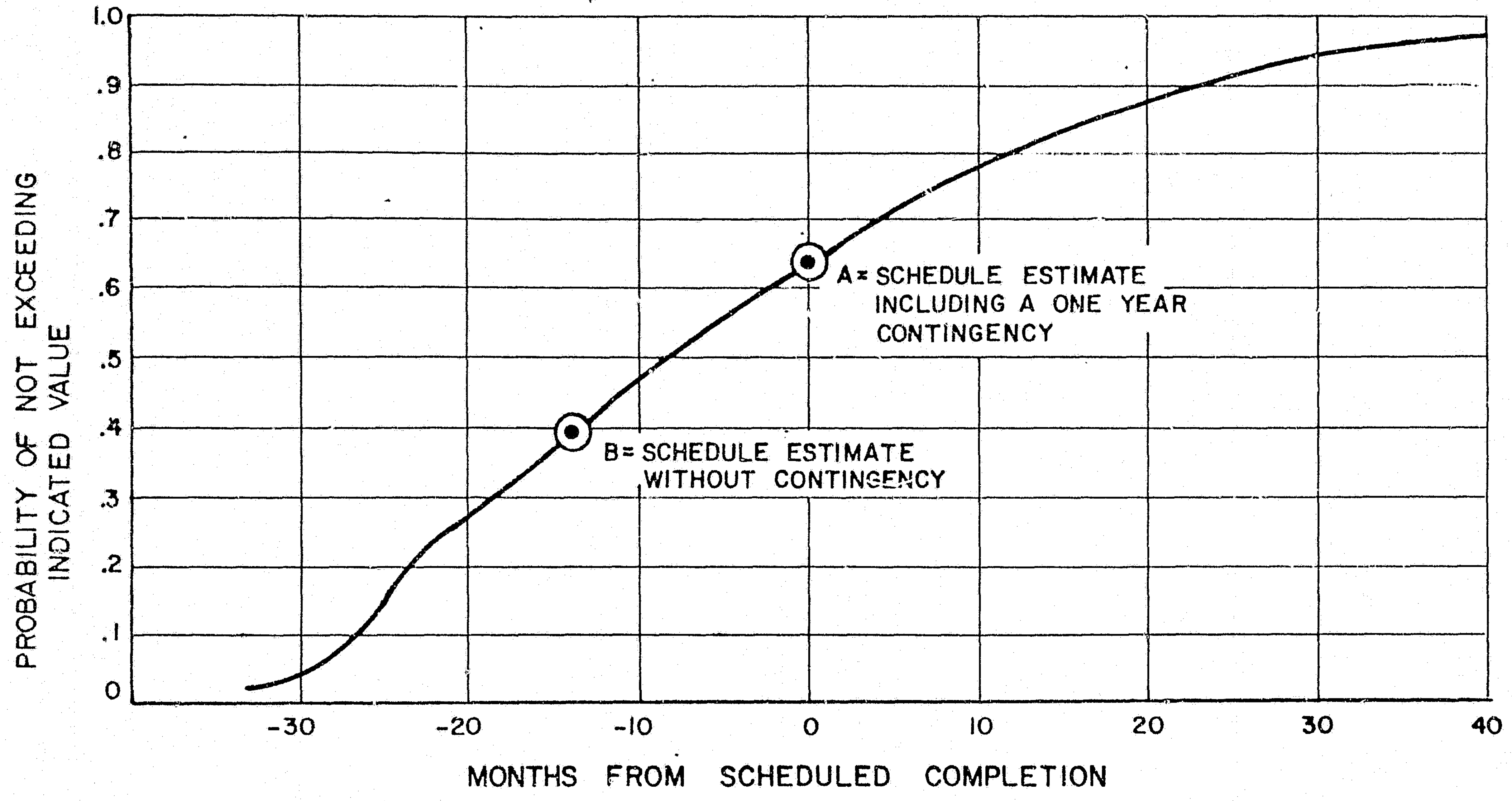

WATANA SCHEDULE DISTRIBUTION

INCLUDING THE EFFECT OF REGULATORY RISKS

FIGURE 2.6

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3 - RISK ANALYSIS METHODOLOGY

SECTION 3 - RISK ANALYSIS METHODOLOGY

3.1 - Introduction

This section defines and discusses the main features of the risk analysis methodology. It describes the key concepts involved in defining the structure of the analysis. Each key concept is discussed separately and is referenced in other sections of the report. The risk analysis discussed here considers a single preferred base plan development for the Susitna Hydroelectric Project.

Table 3.1 outlines the salient features of the risk analysis methodology and how each item relates to the two separate analyses - construction risk and operational (transmission line) risk assessment. Each of these items is discussed at length in the following subsections.

3.2 - States

This study was primarily concerned with the Susitna Project during construction. During construction, the 'state' of the Susitna facilities will be continually changing. When assessing natural risks, such as flood, an average or typical state has to be considered. Long duration activities, such as main dam construction, must be reduced to two or three activities to make the state concept viable.

Operational risk of the project has also been addressed; however, the emphasis was on the transmission system operation and its potential for risk exposure. In this context, Susitna can be associated with a single basic operating 'state.' Consideration was given to various transmission system failure states, but the basic state of analysis remained singular. Contingency plans for coping with loss of power were also developed.

3.3 - Project Components

The risk analysis used three separate project analyses: one for Watana construction, one for Devil Canyon construction, and a third for the entire operational development transmitting power.

Transmission line construction for Watana power was incorporated in the Watana project. Further transmission facilities constructed for Devil Canyon power were part of the Devil Canyon project.

For operational risk analysis, the transmission system has been considered in the following corridor segments:

(1) From Anchorage to the southern terminus of the intertie via Willow (3 single-circuit 345 kV lines)

(2) From Fairbanks to the northern terminus of the intertie via Healy (2 single-circuit 345 kV lines)

(3) From Watana and Devil Canyon dam sites to the connection with the intertie (5 single-circuit 345 kV lines)

(4) The submarine segment in the vicinity of Anchorage crossing Knik Arm (3 single-circuit 345 kV lines).

3.4 - Activities

Activities are the basis of most construction process analyses, as used for Program Evaluation and Review Technique (PERT) or Critical Path Analysis (CPA) assessments.

This study used a coarse activity structure compared to most PERT or CPA assessments, involving about 20 activities for each project. The estimate is a very simple activity structure to facilitate a comparatively detailed treatment of the risks associated with each activity.

In part, the activity structure followed directly from existing plans, for obvious compatability reasons. However, high dollar value activities such as main dam were decomposed to provide useful detail and an average 'state' concept.

In terms of the operational risk analysis, the concept of activities does not apply since the system is in operation.

3.5 - Risks

A preliminary risk list provided a detailed checklist of about 60 risk sources for all activities under five main headings as indicated in Section 4. Inflation was explicity excluded, escalation being defined relative to general inflation. This detailed list was then condensed to 21 risks, as indicated in Section 4.

The simplified or condensed risk structure reflects combinations of similar risks in terms of cause or effect which were not worth separate treatment, risks which are always realized simultaneously, and risks which are secondary effects of other risks. In particular, it was assumed that it was not feasible to pursue detailed risk-by-risk treatment of estimated quantity variations, unit price variations for materials, labor and equipment, productivity variations, extra costs incurred as a consequence of design revisions, external delays imposed on contractors by other contractors and scope changes. All these variations were embedded in a special composite risk, referred to as 'estimate/contract variance.'

Estimate/contract variation was defined to include the effects of more detailed design and scope changes between preliminary estimation (as per the current estimate) and contracting. Assessing the 'estimate variance' risk involved a review of available data on the estimate/bid performance of other projects. It also involved assessment of the firmness of Susitna cost estimates, relative to the other projects considered. Data relevant to estimate variance are reasonably plentiful, but their interpretation in relation to Susitna was not a simple task, and this risk necessarily reflects considerable uncertainty with respect to the appropriate level of estimation variance.

The contract variation portion of this risk was defined to include the effect of refined design during construction delays imposed on one contractor by another contractor, and scope changes between contracting and completion which result in time delays or cost overruns passed on to the owner and not absorbed by the contractor. Assessing the contract variance portion of this risk involved a review of available data on the bid/final cost performance of other projects. It also involved an assessment of the likely performance of the Susitna project in this respect. However, this risk could not be assessed with the same confidence or precision as estimate variance. As a consequence, it necessarily embodies even more uncertainty with respect to the appropriate level of contract variance.

Natural risks such as flood and earthquake were assessed objectively in relation to available data, with subjective input limited to Susitna adjustments. For example, wind data are not available for the site, and nearby sites involve differences which cannot be directly estimated in an objective manner; but nearby site data provide a good objective basis for risk assessment.

Design controlled and construction cost and schedule risks such as seepage/piping were assessed subjectively, using engineering experience plus all available data and literature. Experience is available, for instance, although it is not available in terms of data for identical material under identical circumstances. Construction cost and schedule and human related risks such as labor disputes and contractor capability were assessed subjectively using engineering experience, as data in these areas were limited or non-existent.

Postulated risks, such as vandalism and sabotage, were assessed subjectively after considerable discussion, as data in this area were non-existent or not available.

Eight risks were evaluated for their impact on the transmission system operation. The natural risks which were considered for the transmission system are (1) flood; (2) wind/ice/temperature; and (3) seismic events/slope stability. Risks associated with ice and wind were considered jointly because of transmission line design criteria. Permafrost degradation, geologic conditions, and low stream flow were considered but not treated further because of their anticipated minimal impact on the already-built transmission lines. All of the risks listed under design controlled and construction cost and schedule risks were included in the construction risk analysis and not evaluated here. Among human related risks, consideration was given to the risks associated with sabotage/vandalism. Four additional elements of operational risk associated with lightning, river scour, anchor dragging, and aircraft collision were introduced to complete the transmission line operation risk assessment.

3.6 - Activity-Risks

Each of the 21 construction risks was considered in relation to each of the construction activities. The matrix of possible combinations of construction activity-risks is discussed in Section 4 and presented in Tables 4.6 and 4.7.

Whenever a risk was clearly not applicable in an activity context, or its effects were clearly negligible in terms of the criteria scales of interest, that combination was excluded, the rationale being documented as discussed in Section 4. The remaining activity-risk combinations were identified as 'activity-risks.' For example, cofferdams-flood and main dam excavation-flood were identified as activity-risks.

With respect to risks associated with the activity itelf, the activity-risk concept is exactly as the title suggests. For example, main dam excavation-labor disputes risk is concerned with the effect of labor disputes during the main dam excavation process in terms of the main dam excavation labor force.

However, with respect to natural risks such as flood, a similar interpretation is not possible. For example, main dam excavation-flood treated in this way would ignore the effect of floods on parts of the system completed by previous related activites, such as the construction of the cofferdam. Flood risk associated with the completed cofferdam during main dam excavation must be considered as part of the main dam excavation-flood risk. In the context of natural risks affecting the whole system as completed to that point, activity-risk combinations are in effect subsystem-state-risk combinations. This means, when considering the impact of a realized risk, previous activities associated with the same subsystem had to be considered. For example, the main dam excavation-flood activity-risk embodied the effect of flood on main dam excavation plus the effect of the same flood on the cofferdam and the diversion tunnel, those activities which precede main dam excavation.

Components associated with separate parallel construction paths were kept separate via the subproject divisions. For example, spillway excavation and concreting were treated as part of a separate subproject, and the spillway-flood activity-risk was not embedded in the main dam excavation-flood activity-risk.

Activity-risks were not necessary in terms of the operational risk analysis, since there are no activities per se.

3.7 - Risk Events

Probabilistic analysis began with the definition of a set of credible risk events which represented all reasonable possibilities associated with some of the natural risks. For example, floods were associated with the maximum credible flood as defined by hydrological data, and a range of more likely, less extreme cases.

A common set of risk events for all activity-risk combinations affected by a risk is desirable. All design levels for associated activities were considered when choosing the risk events.

Uncertainty with respect to the assessments of risk event probabilities, and other probabilities, was explicity recognized. The concern was to present consistent unbiased estimates of the correct order of magnitude. Errors in the assessment of probabilities of each risk event which do not reflect consistent error or bias across the risk can be expected to cancel out, making the overall assessment of risk comparatively precise.

Section 4 discusses the technical evaluations of risk on construction activities. Section 4.7 outlines the operational risk evaluation. Section 5 discusses the underlying probability theory and assumptions in relation to the way risk probabilities and quantitative assessments were subsequently used in the formal risk analysis.

While some natural risks can be defined on a per year basis, as just described for flood, this is not true of geological conditions, because an unfavorable condition is either found or not, in relation to the physical area of interest.

Some non-natural risks required a one-time approach; for example, equipment availability. Most others might be viewed in a year-by-year framework, but dependencies between years made this undesirable. For example, contractor capability is not independent from year to year.

When risks could not be considered on an independent year-by-year basis, the risk event concept and associated probability steps were skipped, proceeding directly to the impact concept and probability steps. It was easier to consider these risks directly in their appropriate activity-risk context, without attempting separate risk event assessment.

3.8 - Activity-Risk Events and Probabilities

Construction risk event probabilities produced during the last step were converted to activity-risk events and probabilities for the activity duration. This step was not necessary for the operational risk analysis, since events during operation occur annually. For example, the main dam-excavation flood activity-risk involves two years. Risk event annual probabilities for one year can be defined as shown in Table 3.2.

The P (500) is the probability of a "500 year return period flood," associated with 200 year return period flood levels or worse, 500 being a representative or conditional expected value in the range 200+. Its value of 0.005 was computed as 1/200. The P (100) is the probability of a "100 return period flood," associated with 75 to 200 year return period floods, 100 being a representative or conditional expected value in the range 75 to 200. Its value of 0.008 is the difference between the probability of a flood at the 75 year level or greater and the probability of a flood at the 200 year level or greater. The P(50) was obtained in a similar way, and P(0) as a residual obtained in a similar way.

Given the one year risk probabilities for flood noted above, the two year main dam excavation-flood activity-risk event probabilities are as shown in Table 3.3, where P(50), P (100) and P (500) are for single events, and P

(MULTIPLE) is for more than one 50, 100 or 500 year event occurring during an activity.

3.9 - Impact or Damage Scenarios

Given the realization of a risk event, a number of very different impacts can follow. For example, in the case of an earthquake, if a ground acceleration of 0.5 g is the design level for a facility and a 0.6 g acceleration is experienced, the facility may collapse or it may survive almost undamaged; and there is a range of intermediate possibilities. Moreover, intermediate possibilities may not be amenable to ordering; one may be worse than another in some respects, better in others.

Each scenario was associated with the realization of each activity risk and is described in terms of the physical characteristics of the situation.

Section 4 discusses the scenarios for activity risks and the estimation of probabilities. These probabilities are conditional probabilities which define the chance that each possible impact scenario will be realized given an activity risk event is realized.

A similiar approach to impact scenarios was taken in the operational methodology. However, the scenarios were constrained by the components of the intertie system. Therefore, impact was defined in terms of the most probable risk causing damage to the Anchorage intertie, damage to the Fairbanks intertie, damage to the Susitna intertie and damage to the submarine crossing.

An example of the format and structure of scenarios is shown in Table 3.4, for the Watana main dam excavation-flood activity-risk.

3.10 - Responses

Given the realization of a risk or activity-risk event, consequences may vary because of the nature and level of the damage or other implications. Consequences may also vary as a result of the chosen response. It is important to choose appropriate responses in an operational context. When evaluating a base plan, it is important to assume appropriate contingency plans. For example, if main dam excavation is delayed, the delay might be accepted, or a decision to recover the time lost by increasing the labor force might be taken. If the latter is the best response, and the former is assumed, duration will be overestimated and cost underestimated.

A single response, assumed to be appropriate, was associated with each activity-risk impact scenario. Inevitably some assumed responses will prove questionable. However, alternatives were considered; and, to the extent possible, an attempt was made to ensure all choices were reasonable.

In some cases preventative rather than mitigating responses were identified, and the base plan was changed to incorporate such preventative measures. For example, the risk of low stream flow leading to an inability to test the generation facilities and start producing power as planned was identified as a serious and likely difficulty. Changes were made in schedules for the main dam and for filling the reservoir, thereby reducing the magnitude of the problem.

The purpose of the construction risk analysis was the assessment of the base plan in terms of specific key assumptions, as well as overall cost and schedule considerations.

The operational risk assessment dealt with response to Susitna loss of power.

3.11 - Secondary Risks and Responses

Primary responses may not work out as planned leading to secondary risks and responses. For example, it may not be possible to obtain additional labor. Such secondary risks, and the need for associated responses, were considered. These secondary risks and associated responses were not modeled separately, but have been considered in the assessment of associated activity-risk event/impact/response combinations and the resulting consequences.

3.12 - Multiple Criteria Evaluation

Describing the consequences of an action or event in terms of a single criterion like dollar cost or deviation delay in months is often convenient. However, doing so is often misleading. The joint or simultaneous effect in terms of several criteria may require assessment to allow important insights to be gained.

In the construction risk analysis, separate considerations of three criteria were provided for: activity delay, increased manpower, and additional costs.

Delay was defined in terms of activity duration delay in months. It was used to consider project delay, but delay effects of activity-risks were added directly only within each activity. Project delay assessment used directly computed activity delays, but reflects qualitative consideration of the extent to which activities might be overlapped, accelerated, or resequenced, issues which make direct quantitative assessment somewhat naive.

Increased manpower was defined in terms of the increase in the average labor force over the activity period as a percentage. It was used to consider total project additional labor demand, but increased manpower effects of activity-risks were computed directly only within each activity. Assessment of project manpower demand used these increased manpower demands for activities, but reflects the extent to which activities might be retimed to obtain smooth manpower usage profiles, an issue which makes direct quantitative assessment overly simple.

Additional cost was defined in terms of all direct construction costs in dollar terms. Additional cost effects of activity-risks were computed directly within and across activities, to provide an overall Susitna construction result.

An example of criteria assignment is shown in Table 3.5 for the Construction Risk analysis.

Consequences of a risk event occurrence in the operational risk analysis were described in terms of the number of days which the areas around Anchorage and Fairbanks experienced Susitna power outage. Table 3.6 outlines an example of the operation risk criteria assignment.

3.13 - Criteria Value Distributions

Given the realization of an activity-risk event/impact scenario/response combination, each criterion was associated with a probability distribution. The distribution was defined in terms of three values: a minimum value, a modal (or most likely) value, and maximum value. Minimum and maximum values were associated with a 90 percent confidence band. This means the maximum can be associated with that value exceeded one time in twenty, with a similar interpretation for the minimum. The format and structure of these assessments were as indicated below for the main dam excavation-flood activity-risk.

These three point distribution specifications were used to generate histogram representations of the probability distributions. The scale for delay was months, 150 intervals allowing from zero to 150 months, 12.5 years. The scale for manpower was percent, zero to 150 percent. The smallest scale for dollars was 10 million, scales of 20 and 40 million also being provided, to allow zero to 6 billion dollars to be considered.

Similarly for the operational risk analysis, minimum, modal and maximum values were assigned for each criterion. A maximum of 60 intervals was appropriate for the analysis, corresponding to a total of 60 days of Susitna power loss.

3.14 - Criterion Additivity

Cost variations for all construction activity-risks were added, within activities, then across activities within the Watana and Devil Canyon projects. The cost effects of realizing risks are additive, provided we assume the responses to one risk do not interact with the responses to the second. This assumption is important, but it had to be tolerated for the present study within projects. Watana cost variations were not added to Devil Canyon cost variations, because the scope for responses is too large and undefined for a meaningful result.

Duration variations for all activity-risks were added within activities. They were not added across activities.

Manpower variations for all activity-risks were also added within activities, but not across activities. In addition to the question of response interactions, it would be inappropriate to pursue addition for activities occurring at different points in time. Qualitative treatment of the labor demand and supply implications of these results was the only viable approach.

Days of power lost in Anchorage and Fairbanks were added appropriately for the operational assessment.

3.15 - Dependence Kinds and Types

Many forms of risk analysis, including the operational risk analysis, require that all probability distributions combined be assumed independent. The construction risk analysis required extensive treatment of dependence between activity-risks. Therefore, the discussion which follows relates to the assessment of dependence for construction risk.

Several kinds of dependence are involved. Cost is the most important criterion for dependence assessments with respect to our analysis, so the discussion here will concentrate on dependence between cost distributions.

(1) Cause/effect dependence - separable: consider the pair of risks 'weather' and 'material availability' in the context of the activity 'main dam excavation.' Weather can clearly cause material availability problems in the sense that it may be impossible to extract fill materials under some weather conditions. This level of dependence can be avoided by extracting the associated risk from the material availability risk and embedding it in the weather risk, via appropriate definitions. That is, 'weather' can be defined to include the effect of weather on construction progress in direct terms, and in terms of associated material supply. Weather effects can be excluded from the material supply risk, except where weather in some location and time frame other than that associated with the activity is involved. Alternatively, a non-separable cause/effect dependence approach may be taken.

(2) Cause/effect dependence - not separable: consider the pair of risks 'equipment availability' and 'equipment breakdown' in the 'main dam excavation' activity context. If equipment is difficult to obtain in the required quantities, less serviceable or less appropriate equipment may have to be accepted, and equipment may have to be used harder and longer. This will clearly contribute to higher breakdown rates. However, it is not very useful to define equipment availability in a manner which embodies induced equipment breakdown effects. In principle, it could be done, but in practice it is not very illuminating. In this case 'equipment availablity' was defined to exclude the breakdown implications of availability problems. Such cost implications should be associated with equipment breakdown. Equipment breakdown should have a probability distribution which reflects the full range of possible breakdown levels, including those induced by equipment availability problems. When combining the

availability and breakdown distributions, dependence must reflect the increased chance of higher breakdown cost values if availability problems are realized, the increased chance of lower breakdown cost values if availability problems are not realized.

(3) Common antecedent dependence: consider the pair of risks 'construction quality control' and 'construction accidents,' in the context of 'main dam excavation.' There is no direct relationship between these two risks in the causal sense discussed above. However, both are related to the risk 'contractor capability,' in the sense that a contractor who tends to be good in cost and duration performance terms tends to be good in quality control and accident terms as well. The relationship between capability and quality, and the relationship between capability and accidents, is based upon underlying common antecedents: the reasons why contractors are good, bad, or indifferent. The relationship between quality and accidents is based upon an explicit antecedent: contractor capability. If the contractor is good, quality tends to be good and accidents tend to be low, which implies that accidents tend to be low when quality tends to be good.

(4) Compounding consequence dependence: consider the pair of risks 'ice' and 'flood,' still in the 'main dam excavation' context. Both pose risks for this activity via their effect on the cofferdam. They have some common antecedent dependence, in the sense that floods tend to occur in the spring when ice is melting, and the melting of the ice leads to the breakup which causes ice flow problems. In addition to this dependence in terms of their occurrence, they have a compounding effect in terms of damage. If a large flow hits the cofferdam while it is near overtopping, the extent of the damage and its cost implications are very much greater. It is not just that ice and flood problems tend to occur together. When they occur together, the cost consequences are very much greater than a simple sum of their effects when they occur on their own.

(5) Estimation error dependence: consider two activities which have total costs we would expect to display a very modest level of dependence in terms of the four types discussed above. Assume they involve very similar design problems, construction problems and contracting considerations. Assume the same person or group of people were responsible for assessing the cost. If the estimates have significantly underestimated or overestimated the cost for one, they have probably made a similar error with respect to the other. If the variation potential associated with the activity costs is heavily influenced by estimate variance and contract variance considerations, as defined earlier in this section, a high level of estimate error dependence will be induced. Minimal dependence of this kind should be associated with risk combinations within activities.

3.16 - Dependence Structures

If all risks or activity-risks and associated criterian distributions are independent, the ordering of distribution combinations can be arbitrary. This is true for the operational analysis, where risks occur independently. However, if dependence is associated with activities or activity-risks, the ordering of distribution combinations is very important.

Section 4 discusses how a pair-wise dependence tree was used to define the computation sequence employed to combine all the construction activity-risks considered, first within activities, then across activities. Each pair-wise combination was associated with a percentage level of dependence, from 0 to 100 percent.

When choosing pairs within the activity level, initial pairs were chosen on the basis of the strongest or most clearly defined dependence relationship. For example, within the penstock activity, the following pairs were selected, for the following reasons.

'Geological condition' risk was linked to 'ground water' risk, at a 90 percent level of dependence, because ground water problems were assumed to be very heavily dependent upon geological conditions in terms of a direct causal relationship.

'Seismic risk' was linked to the 'geological condition plus ground water' composite risk, at a 10 percent level of dependence, because these risks are clearly related in terms of the kind of issue involved, but they are very weakly related in causal or statistical terms.

'Equipment breakdown' was linked to 'weather' risk, at a 40 percent level of dependence, because the tendency for equipment to break down as a consequence of working in extreme conditions was thought to be the strongest direct effect of weather not embedded in the weather risk itself, although only a moderate level of dependence was assumed.

'Labor disputes' was linked to 'sabotage/vandalism,' at a 70 percent level, because it was assumed that this was the strongest dependence link for either, the causality direction being obvious.

'Contractor capability' was linked to 'quality control,' at an 80 percent level, because it was assumed that quality control was a direct responsibility of the contractor.

'Construction accidents' was linked to 'contractor capability plus 'quality control,' at a 70 percent level, because it was assumed that construction accidents had a weaker link with contractor capability than quality control, but the link was still a strong one.

'Contractor capability plus quality control plus construction accidents' was linked to 'labor disputes plus sabotage/vandalism,' at a 20 percent level, because a degree of dependence based upon contractor capability skills clearly links all these considerations, although it was assumed to be a weak level of dependence.

'Equipment breakdown plus weather' was linked with 'contractor capability through vandalism,' at a 10 percent level, to capture the last and lowest level of dependence based upon contractor capability skills.

All the remaining links had a zero level of dependence, so the linkages could have been arbitrary.

When choosing pairs across the activity level, the rationale was similar. In addition, some attention was paid to using groupings which make intermediate results of direct interest.

3.17 - List Documentation

The risk and activity-risk event, impact scenario, response, secondary risk and response and criteria information were documentated in predesigned and formulated data lists. An important aspect of the methodology is the way this extensive and diverse body of information produced by a large number of different people becomes an integrated basis for analysis. Regular review and the use of word processing storage and computer data files to keep documentation up to date are important aspects of this process for both the construction and operational risk assessments.

3.18 - Computer Software

Modifications to computer software previously developed by Acres and British Petroleum (BP) were made to accommodate the special nature of the structure used for this study. This software allows very large volumes of input data to be assembled and maintained efficiently and allows computations to proceed in a flexible manner with minimal intervention. Further, a wide range of presentation forms, formats and levels of detail for results were specified.

Section 5 discusses the computations involved and associated computer software features. Essentially, two forms of the risk program were used, each appropriately modified for the construction analysis and the transmission line operation analysis.

TABLE 3.1: SALIENT FEATURES OF RISK ANALYSIS METHODOLOGY

Item	Susitna Project Construction Risk Analysis	Transmission Line Operational Risk Analysis
States:	During construction of Watana site and Devil Canyon site.	During operation of the Railbelt intertied transmission system with a 1280 MW Susitna Basin Development.
Project Components:	1. Watana site and associated transmission lines. 2. Devil Canyon site and associated transmission lines.	1. Anchorage Intertie 2. Fairbanks Intertie 3. Susitna Intertie 4. Submarine Section
Activities:	Construction activities.	Not applicable.
Risks:	Construction related risks.	Operation related risks.
Activity-Risks:	Risks that apply to certain activities differently.	Not applicable.
Risk Events:	Annualized probability of construction risk events.	Annualized probability of operation risk events.
Activity-Risk Events and Probabilities:	Scaled annual probabilities to activity durations.	Not applicable.
Impact Scenarios:	Relate various levels of impacts on activities to risk events.	Relate various levels of impacts on the intertie components to risk events.
Responses:	Response to construction risks in terms of cost and schedule criteria.	Response to operation risks in terms of days of power lost.
Secondary Risks and Responses:	Considered in primary response.	Considered in primary response.
Multiple Criterion Evaluation:	Evaluated impact/response in terms of 1. Activity delay (months) 2. Labor increase (%) 3. Additional cost ($M)	Evaluated impact/response in terms of 1. Days of 50% power loss to Anchorage. 2. Days of 100% power loss to Anchorage 3. Days of 100% power loss to Fairbanks.

TABLE 3.1: SALIENT FEATURES OF RISK ANALYSIS METHODOLOGY (Cont'd)

Item	Susitna Project Construction Risk Analysis	Transmission Line Operational Risk Analysis
Criteria Value Distributions:	Assumed minimum, model and maximum value distributions for each criterion.	Same.
Criterion Additivity:	Like criterion added within activity - risks; cost criterion added across activities.	Like criterion added for all risks.
Dependence Kinds and Types:	1. Cause/effect - separable 2. Cause/effect - not separable 3. Common antecedent 4. Compounding consequence 5. Estimation error.	All risks defined as independent risks. (0% dependence)
Dependence Structure:	Pairing of activity-risks using percent dependent adds.	Independent adds (0% dependence)
Computer Software:	Risk Analysis Program Version II	Risk Analysis Program Version I (modified)

TABLE 3.2: RISK EVENT PROBABILITIES

Probability Event			Annual Probability	
P (0)	= 1.0 - 0.04	=	0.960	= P (NO EVENT)
P (50 yr)	= 0.04 - 0.013	=	0.027	= P (MINOR FLOOD)
P (100 yr)	= 0.013 - 0.005	=	0.008	= P (MODERATE FLOOD)
P (500 yr)	= 0.005 - 0	=	0.005	= P (MAJOR FLOOD)
			1.000	

TABLE 3.3: ACTIVITY-RISK EVENT PROBABILITIES FOR A 2-YEAR DURATION

P (0)	$= 0.96^2$	= 0.9216	P (NO EVENT)
P (50)	$= 2 \times 0.027 \times 0.96^2$	= 0.0498	P (MINOR FLOOD)
P (100)	$= 2 \times 0.008 \times 0.96^2$	= 0.0147	P (MODERATE FLOOD)
P (500)	$= 2 \times 0.005 \times 0.96^2$	= 0.0092	P (MAJOR FLOOD)
P (MULTIPLE)	= 1 - P(0)-P(50)-P(100)-P(150)	= 0.0047	P (MULTIPLE FLOOD)
		1.0000	

TABLE 3.4: ACTIVITY-RISK CONDITIONAL PROBABILITIES

Impact Scenario	(Flood Level) Activity-Risk Event: No Event		Minor		Moderate		Major		Multiple	
	P	sumP	P	sumP	P	sumP	P	sumP	P	sumP
NEGLIGIBLE	1.00	1.00	.99	.99	.05	.05			.01	.01
SLIGHT			.01	1.00	.90	.95	.05	.05	.50	.50
SUBSTANTIAL					.05	1.00	.10	.15	.45	.95
CATASTROPHIC							.85	1.00	.04	1.00

TABLE 3.5: CONSTRUCTION RISK CRITERIA ASSIGNMENT

Impact/ Response Scenario	Delay (Months)			Increased Manpower (Percent)			Increased Cost ($1,000,000)		
	Min	Mode	Max	Min	Mode	Max	Min	Mode	Max
NEGLIGIBLE	0	0	0	0	0	0	0	0	0
SLIGHT	0	1	3	0	1	3	0	1	3
SUBSTANTIAL	2	9	15	2	9	15	2	9	15
CATASTROPHIC	12	36	50	12	36	50	12	36	50

TABLE 3.6: OPERATION RISK CRITERIA ASSIGNMENT

Damage to Components	Percent Susitna Power Lost		
	1 Line	2 Lines	3 Lines
Anchorage Intertie	Anchorage Loss 0%	Anchorage Loss 50%	Anchorage Loss 100%
Fairbanks Intertie	Fairbanks Loss 0%	Fairbanks Loss 100%	-
Susitna Intertie	Anchorage Loss 0% Fairbanks Loss 0%	Anchorage Loss 50% Fairbanks Loss 100%	Anchorage Loss 100% -
Submarine Segment	Anchorage Loss 0%	Anchorage Loss 50%	Anchorage Loss 100%

4 - TECHNICAL EVALUATION

4 - TECHNICAL EVALUATION

4.1 - Introduction

This section presents the basis of the technical evaluation on which the formal computer-aided risk analysis was done. The technical evaluation consists of the following:

(1) Review of the base plan construction cost and schedule
(2) Review of the base plan design criteria
(3) Development of a risk list
(4) Development of a construction activity list
(5) Definition and assessment of activity risks
(6) Development of an activity-risk matrix
(7) Development of activity-risk descriptions
(8) Development of impact-response assessments for each activity risk

4.2 - General

The review of the Susitna base plan was based on the project documents as listed in the list of references at the end of this section.

4.3 - Basis of Analysis

The Susitna risk analysis is based on the following conditions and assumptions:

(1) The risk analysis will assess the impacts of risks during the construction period in terms of construction schedule and cost variances and the impacts of risks to the transmission system during operation of the Susitna project.

(2) The Susitna project will be considered as two subprojects: Watana and Devil Canyon site developments. Watana and Devil Canyon have been broken down into construction activities, respectively. See Table 4.1 for a list of the activities. Because of the significance of the main dam for both Watana and Devil Canyon in duration and in cost, it was broken down further into sub-activities. These activities provided the level of detail for analysis and interpretation.

(3) The construction activities were taken directly from the Watana and Devil Canyon construction schedule. The activity costs were taken from the Updated Cost Estimate dated October 1981 and allocated to the activity by percentages and shown in Table 4.1. Where the activity costs were combined or broken down from the cost estimate, they have been so noted in remarks in the table. The activity durations are tabulated in Table 4.2.

(4) Each of the risks are evaluated on the effects of a particular construction activity. Where there is a significant activity-risk combination, they have been identified in an activity-risk matrix (Tables 4.6 and 4.7). Those combinations that have not been identified are either illogical combinations or have been considered insignificant. In either case, supporting discussion is presented for a particular activity-risk combination.

(5) Each of the risks is considered with a particular activity during a period of the construction that would tend to average the impact of the risk over that activity duration. This approach will tend to understate the effects of risks beyond this point in time and conversely overstate those before it. However, this approach is necessary for simplification of the analysis. A further level of detail would be to break the 22 major activities into as many subactivities as required for presentation of results. Another approach would be to evaluate the risk as a moving time line as construction progresses. This is useful with cash flow, financing, and insurability of the project. This approach was not chosen for this analysis since the level of detail in this study would not be commensurate with such a rigorous analysis. However, these approaches should be considered in future analysis of construction risks.

(6) The technical evaluation will first consider the signficance of a risk and then the significance of the risk on a particular activity during construction. The evaluation of the activity will be based on expressing the risk assessment in terms of average or typical risk exposure at some time during the activity duration. Conceptually, the risk exposure during an activity will be changing with time wherein the risk exposure at the very beginning and end of an activity is essentially zero but will increase to a maximum and then decrease.

4.4 - Development of Risk List

The initial risk list was developed from a review of the Susitna base plan, construction schedule and construction cost estimates and from discussions with key members of the Susitna project team. This initial list is presented in Table 4.3. The risks were grouped into appropriate categories. This comprehensive list of risks includes risks which could occur during the construction or operation period or both. For the risk analysis concerned predominantly with the risks during the construction period, the risk list has been pared down to that shown in Table 4.4. In doing so, some risks, and consideration thereof, have been included in the definition of other risks or have been noted as a consequence of other risks. Still other risks have been dropped because of their insignificance.

A list of risks associated with the transmission line operation is shown in Table 4.5.

4.5 - General - Watana and Devil Canyon

The construction activities for Watana and Devil Canyon were listed in Tables 4.1 and 4.2, taken directly from the Construction Schedule SK-5700-M9-001 and -002 Rev 9 dated 11/20/81. This intially defined the smallest level of detail for investigating construction cost and schedule risks.

Subsequently, due to its importance, long duration and significant cost, the main dam for each site was broken down further.

Watana Main Dam

5a - Excavation - from start (mid 1986) to finish (end of 1988) of excavation

5b - Fill I - From start of impervious fill (beginning 1989) to start of impoundment (early 1991)

5c - Fill II - From end of Fill I to completion

Devil Canyon Main Dam

5a - Excavation - From start (early 1992) to finish (end 1994) of excavation

5b - Concrete - From start (beginning 1995) to finish (late 1998)

For purposes of grouping these activities into broader categories and for relating activities which are dependent on other activities in terms of construction cost and schedule, the activity groups are:

Activity Group	Activity
Site Mobilization	Main Access Site Facilities
River Control	Diversion Tunnels Cofferdams
Main Dam	Main Dam (Watana) Excavation Fill I Fill II
	Main Dam (Devil Canyon) Excavation Concreting
Saddle Dam	Relict Channel (Watana) Saddle Dam (Devil Canyon)

Dam Facilities	Main Chute Spillway Emergency Spillway Service Spillway Tunnel
Powerhouse Facilities	Intake Penstocks Powerhouse Transformer Gallery Tailrace/Surge Chamber
Power Generation System	Turbine/Generators Mechanical/Electrical System Test and Commission
Transmission System	Switchyard Transmission Lines

(a) Watana and Devil Canyon Cost Estimate

The cost data which were used for the risk analysis consisted of the percent of direct cost for each activity. The values are shown in Table 4.1. The costs for the main dam were broken down into proportion of the duration of the three phases. No costs are incurred for impoundment and the costs for test and commission are included in mechanical/electrical systems. The costs for contingency and for owner's engineering are excluded.

(b) Watana Construction Schedule

The overall duration for Watana is 9 1/2 years after the expected issuance of the FERC license in the beginning of 1985. The target milestone is four units on line at the end of 1993. At this time, the only activities yet to be completed are the turbine/generator and associated mechanical/electrical systems installations for Units 5 & 6.

All of the activities shown in the schedule were evaluated for impacts of risk. However, there are a few cases where assumptions were made to simplify the analysis yet still account for their effects. These cases are during the diversion tunnel and transmission line activities.

The construction of the diversion tunnels is broken into two phases: the first phase is the excavation and concreting of both upper and lower diversion tunnels; the second phase is concurrent with the main dam construction during which time the upper and lower tunnels are closed to allow impounding to begin. The risk evaluation of the diversion tunnels concentrated on the first phase since it will present the most significant impact of risks from flood, geologic conditions, ground water, etc. During the second phase the work will involve closing the tunnels which would not tend to have unique construction problems other than flood. Should extreme events of extreme events of flood occur, the amount of damage would be minimal and the time lost is time waiting for the flood waters to recede, usually a few days.

During this time, the placing of fill on the main dam is continuing and is as critical, if not more, than the closing of the diversion tunnels. Therefore, the first phase of the diversion tunnels has been evaluated in the diversion tunnel activity, and the second phase has been evaluated during the placing of fill on the main dam.

The construction of the transmission line is also broken down into two phases. The first phase is the installation of construction power whereas the second phase is the installation of the permanent transmission facilities. Because the development of construction power is more directly associated and concurrent with site facilities, it has been treated with the evaluation of site facilities.

There are three paths in the Watana construction schedule that are in competition for the critical path. These paths are either through the main dam or through the powerhouse. The intent in the scheduling of the construction activities is to keep the critical path through the main dam. The three paths are:

(1) Site Mobilization to River Control to Main Dam to Impoundment to Test and Commission.

(1a) Site Mobilization to River Control to Main Dam to Test and Commission

(2) Site Mobilization to River Control to Powerhouse Facilities to Turbine/Generators to Test and Commission

These paths are shown below with the activities, activity duration and duration on critical path.

Critical Path 1	Total Duration (Months)	Duration on CP (Months)
Main Access or Site Facilities	33.5	18
Diversion Tunnels	21.5	2
Cofferdams	10	6
Main Dam Excavation	30	21
Main Dam Fill 1	28	28
Impoundment	41	18
Test and Commission	21	15

Critical Path 1a

Main Access or Site Facilities	33.5	18
Diversion Tunnels	21.5	2
Cofferdams	10	6
Main Dam Excavation	30	21
Main Dam Fill 1	28	28
Main Dam Fill 2	30	18
Test and Commission	21	15

Critical Path 2

Main Access or Site Facilities	33.5	18
Diversion Tunnels	21.5	2
Tailrace/Surge Chamber	36	12
Powerhouse	69	33
Turbines/Generator	45.5	27
Test and Commission	21	15

As stated before, the critical path of interest and design is the one through the main dam, i.e., (1) or (1a). The path through the powerhouse, if determined to be critical from this analysis, should be accelerated up to remove it from competition with the main dam.

Other near critical activities, based on a review of the schedules, are:

(1) The main chute spillway must be completed before commencing with test and commission.

(2) The service spillway tunnel and intake must be completed before the end of 1991 as a precedent to impounding to El. 1850.

For the purposes of this risk analysis, we will concern ourselves with the three critical paths previously mentioned.

(c) Devil Canyon Construction Schedule

The overall duration for Devil Canyon is 10 years with four units on-line by end of 1999. The schedule for Devil Canyon is not as critical as Watana since 10 years is more than enough for the scheduled work. However, to the extent that resources (men, material and equipment) could be mobilized on Devil Canyon as work is phasing out on Watana, this would provide a continuous transition into Devil Canyon construction. Since the on-line date in 1999 is the target date and since sufficient time exists, the computed potential schedule delay is not crucial to the Susitna project. However, the purpose of analyzing the schedule risk is to determine the relative importance of the critical and near-critical path activities and which activities should be moved up if a potential for delay exists. Devil Canyon commences in 1990, but the significant work load commences in late

1991 and early 1992. Therefore, there would appear to be at least one year margin at the outset. To the extent that the activity durations have an allowance because they are scheduled during Watana construction, this may also contribute further to this margin.

The Devil Canyon construction schedule, as with Watana, relates to two primary critical paths: through the main dam and through the powerhouse.

These paths are described below by listing the activities on each path, the total scheduled duration and the portion on the critical path.

Critical Path 1	Total Duration (Months)	Duration on CP (Months)
Site Facilities	47	9
Diversion Tunnels	22	22
Cofferdams	9	9
Main Dam Excavation	33	21
*Main Dam Concreting	46.5	38
Impoundment	17.5	12
Test and Commission	12	9

Critical Path 2		
Site Facilities	47	9
Diversion Tunnels	22	12
Tailrace/Surge Chamber	33	33
Powerhouse	68.5	30
Turbine/Generators	33.5	27
Test and Commission	12	9

As stated for Watana, the critical path must be through the main dam. If the powerhouse path becomes critical, then those activities on the powerhouse path must be accelerated.

4.6 - Construction Risk Definition and Assessment

This section will define the general characteristics of each risk, will further define the specific nature that each risk will have on the appropriate construction activities and will describe briefly the consequences (impacts/responses). The activity-risks which have been analyzed in the computer aided risk assessment are shown in Tables 4.6 and 4.7 for Watana and Devil Canyon, respectively.

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* Concurrent with closing of diversion tunnel and main dam, concreting and diversion plug must reach the stage of construction to allow impounding to begin.

(a) Flood

There are two types of floods in Alaska: floods caused by snowmelt and floods due to rainfall (summer floods). Snowmelt floods generally occur in May, June, or July while floods caused by rainfall occur in the summer months through September. In a given drainage basin the volume and maximum discharge of a snowmelt flood are functions of the amount of winter snowfall, the temperature during snowmelt, and the rainfall occurring during the snowmelt period.

Annual maximum floods have been measured at a number of river locations in Alaska; two such gaged locations are at Denali and Gold Creek on the Susitna River. Using the discharge data flood frequency, analyses have been performed for these sites. The data was then adjusted to give flood frequency curves for the Watana and Devil Canyon sites.

Since these sites are within the same drainage basin and have similar drainage areas (5760 and 5010 square miles), as one would expect, the flood magnitudes are very similar for given return periods, assuming natural conditions.

The maximum probable flood studies for Watana have shown the maximum probable flood to be 315,000 cfs. In assessing the impacts on construction activity-risks due to various floods, it is fundamental that water levels be established for flood events occuring during the schedule of a construction activity. Damage to that activity will occur only if the water level exceeds the elevation of the construction activity. In this context, the protection afforded a construction activity must also be taken into account. For instance, a cofferdam protects main dam construction. However, if the water level exceeds the cofferdam crest, damage to the main dam may result.

Flood impacts were assessed at Watana and Devil Canyon under three conditions: natural, during diversion, and during impoundment. Under natural conditions, the tailwater rating curves relating given discharges to water levels were used. During the diversions, new water level-discharge relationships were derived for the tunnel flow. For impoundment, it was assumed that the water level was always maintained such that a given return period flood volume could be stored, less the volume discharged through the diversion tunnels during the flood. The affects of larger return period flood volumes were then assessed.

Construction activities considered being exposed to flood risk are as follows:

Watana

- Main Access
- Diversion Tunnels
- Main Dam
- Tailrace/Surge Chamber

Devil Canyon

- Diversion Tunnels
- Main Dam
- Outlet facilities
- Tailrace/Surge Chamber

Flood Event Risk Level	Probability
<50 yr	0.98
50 - 200 yr	0.015
200 - 800 yr	0.00375
>800 yr	0.00125

In assessing flood impacts at Devil Canyon, advantage was taken of flood routing at the completed Watana Dam.

(b) Ice

Ice can affect construction activities at Watana and Devil Canyon in two ways. The most potentially damaging form of ice and that of most concern is river ice. Ice as a result of freezing rain is a construction nuisance and is considered a weather risk.

Minimal river ice data exists for the Susitna River basin, especially during the freezeup process occurring in early winter. However, historic ice thickness measurements have been made at Gold Creek. These measurements, dating back to 1950, indicate maximum ice thicknesses have varied from 2.8 to 5.7 feet. Measurements taken on the Susitna River near the project sites during the 1980-1981 field data collection program showed a maximum ice thickness of 5.6 feet at Watana and 3.2 feet at upper Devil Canyon. There was a 23 foot thickness at Devil Canyon, but this was not an ice cover thickness. Maximum ice thicknesses at other locations along the river varied from 2.6 feet to 10.0 feet with the average maximum being about 4 1/2 feet. Comparing the 1980-1981 ice season would yield an extreme average maximum ice thickness of about 10 feet.

In investigating the risks of river ice, the potential for ice jamming is important. However, personnel from the Alaska Railroad have indicated that over the past twenty years there has been no serious flooding or ice jamming related to ice cover development on the Susitna.

Where river ice will have an effect on a construction activity only during a flood it was incorporated in the flood risk.

Ice that occurs in the form of freezing rain may have an effect on transmission lines and outside construction activities such as the main spillway. However, it was assumed that the annual number of freezing rain storms is minimal and the effect is for a short time only. Thus there will be no significant cost or schedule risk.

A number of activities can be easily dismissed as not being affected by river ice if they are inaccessible to river ice during a flood. The construction activities which will be affected by river ice are as follows and are evaluated in the flood risk.

Watana	Devil Canyon
• Main Access	• Diversion Tunnel
• Diversion Tunnels	• Main Dam
• Main Dam	• Outlet Facilities
• Tailrace/Surge Chamber	• Tailrace/Surge Chamber

(c) Wind

Wind speeds reported in the project design criteria (Table 3.3) for the years 1975 and 1976 were less than 45 mph measured at Talkeetna and Summit stations. The AEIDC (Arctic Environmental Information and Data Center) reported extreme wind speed, for the area including the Watana and Devil Canyon sites, of 60 mph for a 100, 50 and 25 year mean recurrence interval. Speeds of 50 mph and 40 mph are reported for 10 and 2 year mean recurrence interval respectively. These reported wind speeds are moderate and within the conventional design criteria for design of structures for the project.

Risk posed by wind is limited to minor temporary interruptions caused by blown down trees, utility poles and possibly construction cranes at the project sites.

Except for the transmission line construction activity for the Watana project, which extends into higher wind speed zones, the risk due to wind may reasonably be considered of negligible effect on cost and schedule. Therefore, wind was dismissed as a risk during all other construction activities.

Transmission lines extend from the project site to the Anchorage and Fairbanks regions. The AEIDC reports extreme winds in those regions with probabilities as follows. Those wind speeds are expected to pose a potential risk on the transmission line construction activity for both Watana and Devil Canyon.

Wind Risk Level	Probability
No Risk (<70 mph)	0.80
Minor (70-80 mph)	0.15
Moderate (80-100 mph)	0.03
Extreme (>100 mph)	0.02

(d) Seismic Events

A seismic event may pose a considerable risk as the project is located within the seismic risk zone 3, which is characterized by major damage corresponding to intensity VIII and higher on the MM Scale. During an earthquake, the earth's crust oscillates randomly for a period of time which may cause failure in most structures within the project with which may cause failure in most structures within the project with such associated phenomena as ground shaking, ground rupture, liquefaction, and differential movement. Tsunami, a seismic tidal wave, is not being considered a potential risk as the project is located more than 120 miles from the nearest coastline.

Measureable movement along several geologic faults and other significant features present in the vicinity of the project indicates that the area has been seismically active in recent times. Some of these faults are: Denali Fault (250 miles long, recent displacement substantial), Totschunda Fault (54 miles long, recent displacement moderate), Castle Mountain Fault (124 miles long, recent movement noticeable), and several shear zones. The Benioff Zone, which represents seismic activity associated with plate tectonics, is well developed along the Aleutians and is located approximately 55 miles beneath the project area.

Estimated return periods for earthquakes of various magnitude vary in this area depending on the geological feature which is assigned responsibility for originating the event. Due to a wide scatter in the values of the return period, the probabilistic approach based only on a magnitude did not provide an adequate criterion for design. Therefore, another approach based on the values of maximum credible ground acceleration was utilized in estimating return periods as follows for Watana and Devil Canyon.

Watana Maximum Ground Acceleration Risk Level	Probability
≤ 0.30 g	0.9966
0.45 g	0.0029
0.55 g	0.0004
≥ 0.63 g	0.0001

Devil Canyon Maximum Ground Acceleration	Probability
< 0.35 g	0.9985
0.45 g	0.0010
0.55 g	0.0004
> 0.63 g	0.0001

The project design has been developed such that the structures would be able to successfully sustain seismic events. Most structures are founded on rock which should perform adequately under seismic loading. The underground or partially buried structures should be able to derive confining security from the surrounding rock.

The design has been developed based on maximum ground acceleration as derived from mean peak ground acceleration. All critical (water retaining) structures have been designed for 0.47 g (Watana) and 0.55 g (Devil Canyon) representing 84 percentile results of the mean peak ground acceleration; other structures have been designed for 0.3 g (Watana) and 0.35 g (Devil Canyon).

The possibility that an earthquake would adversely affect the structure always exists. Landslides could be triggered and other earth movements initiated by an earthquake. Ground rupture and differential movement could cause structural foundation failure. Temporary support may collapse in excavation where excessive inflow of ground water may cause further damage. Partially built structures could be severely damaged by the ground motion.

All construction activities for both Watana and Devil Canyon would experience the impact of a seismic event except cofferdams, impoundment and Test/Commission. Since their duration is so small, the probability of a seismic event during that time is very small. The extent of this damage will significantly depend on the maximum ground acceleration felt in this area.

Permafrost deterioration involves a decrease in thickness and/or areal extent of permafrost because of either natural or man-made causes. In the project area, certain construction activities are likely to disturb thermal equilibrium and cause degradation of permafrost. Associated with the process of permafrost degradation are the reduction in strength and bearing capacity of the ground, seasonal movement due to frost action, frost heave and thaw settlement, uncontrollable erosion, and other such phenomena which pose a definite risk during the period of project construction and beyond. Activities that may impact permafrost are:

- Main Access
- Main Dam
- Intake
- Transmission Line

The project is located within a mountainous area where permafrost underlies in isolated masses. Thermal probes installed during geotechnical exploration have indicated the presence of permafrost conditions in the south (left) bank of Susitna River at relatively shallow depth. No evidence of permafrost condition has been noticed on the north bank although the ground temperatures are believed to be close to the freezing point.

Based on these conditions, permafrost deterioration was not considered an important risk during Devil Canyon construction.

During construction such phenomena, as change of terrain conditions, removal of insulating vegetation cover, and construction activity would eventually cause permafrost degradation or deterioration in the project area to a substantial depth. The probability of the permafrost deterioration has been estimated as follows:

Permafrost Deterioration Risk Level	Probability
Major Deterioration	0.89
Moderate Deterioration	0.10
Minor Deterioration	0.01

(f) Geologic Conditions

The interpretation of subsurface conditions present in project area has been made on the basis of the information available through a number of sources which included the previous work on the project, existing literature on the area, and first part of the proposed two-phase geotechnical exploration program. The geologic conditions thus construed provided engineering information for the development of project design, construction methods, and cost estimates. The fact that these geologic conditions are generalized only on the basis of limited knowledge, and that the geologic conditions encountered during construction may be appreciably different may require revision of the design, construction methods, and cost estimates.

These three possibilities are actually encountered geologic conditions:

- Condition that would simplify design, minimize hazards, and economize on construction costs.
- Condition that would not require changes in existing design, construction methods, and costs.
- Condition that would require design changes, create construction hazards, and increase costs.

Activities that can be impacted by geologic conditions are:

Watana

- Main Access
- Diversion Tunnels
- Main Dam
- Main Spillway
- Emergency Spillway
- Outlet Facilities
- Intake
- Powerhouse

Devil Canyon

- Diversion Tunnels
- Main Dam
- Saddle Dam
- Main Spillway
- Intake
- Powerhouse
- Tailrace/Surge Chamber

The probabilities of encountering various geological conditions have been evaluated as follows:

Geologic Conditions	Probability
As Anticipated	0.80
Superior than Anticipated	0.10
Inferior than Anticipated	0.10

(g) Low Streamflow

Low streamflow will have no effect on construction activities except impoundment. If the streamflow is low, the reservoir at Watana may not be sufficiently full to permit test and commission to start on schedule. This could then lead to a delay in the on-line date. Even if the units can be tested and commissioned on schedule, there is the possibility that the reservoir may not be full to the normal operating level.

Review of filling criteria for Devil Canyon reveals that no major impacts on schedule will occur from low streamflow.

Thirty years of synthesized flow data exist for both Watana and Devil Canyon. The data for Watana have been compiled into a set of annual volumes. The mean annual volume was computed to be 5.68 million acre-feet and the corresponding standard deviation was 0.757 million acre-feet. For the risk analysis, the normal distribution was assumed for annual and monthly volumes; and using the central limit theorem, volume probabilities were computed.

The Watana reservoir will require 9,515,000 acre-feet to fill to normal maximum operating level. Of this volume, 5,300,000 acre-feet will be dead storage.

The reservoir filling criteria have been established such that the water level of the reservoir during impoundment will not exceed that required to maintain sufficient storage for the 100 year flood volume less the volume discharged during the 100 year flood.

Taking the monthly Watana streamflow record and assuming normal distributions for each month, the probability of the reservoir not being sufficiently full to permit test and commission was computed as 0.236. Therefore, the probability of filling is 1 - 0.236 or 0.764. Probabilities for other low streamflow levels are as follows:

Streamflow Risk Level	Probability
As expected	0.764
Low	0.036
Lower than expected	0.200

(h) Seepage/Piping/Erosion

The uncontrollable seepage through foundations, abutments, and dam section is recognized as a potential risk to the earth structures. The hazards by seepage may be posed in two ways: (1) the seepage water could cause excessive hydraulic pressures and which may result in either heave or loss of material strength causing instability of the structure, and (2) the localized and concentrated seepage progressively develop piping which may cause extensive cavitation and erosion in the structure eventually resulting in the release of water from reservoir.

The design of both the cofferdams and the main dam provides for an impervious core of clay material in order to resist the seepage of water through the structure. In addition, the wide section of the dam would provide a long path to seepage water thus reducing gradient of hydraulic pressure. The seepage through foundation would be minimal because both the cofferdam and the main dam are bearing on the competent bedrock of excellent quality. Where the bedrock is incompetent, extensive grouting and other foundation preparations are planned to make the rock strong and impermeable.

Assuming that the design has been developed adequately to prevent seepage through the foundations or the structure, the possibility of appreciable seepage exists in the construction activities of cofferdams and main dam for Watana and Saddle Dam for Devil Canyon. The probabilities for the seepage have been evaluated as follows:

Seepage Risk Level	Probability
Minor or no seepage	0.90
Moderate seepage	0.05
Major seepage	0.05

(i) Ground Water

The potential infiltration of ground water either from the layers of granular soils in the glacial/alluvial overburden, or through discontinuities within the underlying bedrock is recognized as a potential risk during excavation activities. Large volumes of water encountered during construction may result in unnecessary increases in construction costs.

Limited information is available relative to ground water in the project area. The piezometers were installed during the geotechnical exploration program, and their continued readings will enable better evaluation of the ground water regime in the future. At present, evidences indicate a shallow to deep ground water table which can be assumed as a subdued replica of areal topography . The ground water gradients are interpreted as sloping towards the Susitna River and its tributaries.

In the absence of detailed information on ground water, it has been assumed that excessive ground water will most likely be encountered during construction requiring substantial changes and modification in the construction procedures. The probabilities of encountering ground water during excavation have been evaluated as follows:

Watana

- Main Access
- Diversion Tunnels
- Main Dam
- Powerhouse

Devil Canyon

- Diversion Tunnels
- Main Dam
- Powerhouse
- Tailrace/Surge Chamber

Ground Water Conditions	Probability
No ground water encountered	0.05
Moderate ground water encountered	0.20
Major ground water encountered	0.75

(j) Equipment Availability

An equipment requirement list has been developed by R&M Consultants. The list includes the type and number of each item of equipment required for each project: Watana and Devil Canyon. The list was reviewed for type of equipment, the quantity of each construction activity, and the major uses for each type of equipment.

With the exception of some major equipment, most of the listed equipment may be considered as readily available. Therefore, the equipment is categorized as either readily available equipment or equipment requiring lead time and special ordering procedures. The readily available equipment is considered to have insignificant effect on the project with regard to its initial availability and replacement during project construction. The remaining types of equipment are considered to require investigation in terms of the effect of availability on the project schedule. In the course of the investigation, the main factor considered is the available lead time between the date of issuance of the FERC license and the date scheduled for first use.

Equipment considered as readily available includes:

- Pick up trucks
- Dozers
- Dump trucks
- Graders
- Rollers
- Pavers
- Truck mixers
- Mobile cranes
- Front end loaders
- Truck mounted concrete pumps
- Excavators (dozers, backhoes)

Construction equipment considered as special order includes:

- Power generators
- Living quarters and supporting facilities
- Treatment plant
- Tunneling machines
- Shotcrete batch plant
- Sheet piling dr
- Rockcrusher
- Concrete batch planc
- Tower cranes

Review of the project schedule indicates that the first activities are mainly construction of access roads and site facilities. Equipment required for construction of access roads is considered readily available and should not pose a risk to project schedule. The construction of site facilities which includes camp housing and other living facilities and plant equipment such as rock crusher and concrete batch plant and which begins 6 months after start of construction does not present any severe problems on the lead time or type of equipment required.

Except for the construction of the diversion tunnels, which is scheduled to commence 6 months from the start, all other activities are scheduled to start about 18 months from the start. This 18 month period is sufficient to purchase, fabricate, ship and erect all equipment and installations required for these activities. The lead time for all required equipment was confirmed to be sufficient by the equipment suppliers which were contacted. The diversion tunnels require tunneling machines, which have a 7 to 12 months lead time.

Preplanning the purchase of such equipment is required. The schedule indicates that the tunneling machines may not be required until all the front end activities of excavating the portals are completed. This would allow a period of about 8 months from the starting point to the first need of the tunneling machines. Information obtained from tunneling machine suppliers indicate that the lead time varies depending on the type of machine required. Information also indicates that tunnel boring is preferred over drill and blast approach. Lead time required for design and fabrication of tunneling machine is estimated to be 7 to 12 months. This lead time seems to be critical unless early commitments are made for purchase of the machines. Another possibility is reconditioning used machines which are available to large tunneling contractors. Provided a machine is available, the lead time is 4 to 6 months.

Based on the above information, the equipment requirements and available utility, it can be concluded that the tunneling machines for the diversion tunnels might pose a risk in terms of availability.

Diversion Tunnel Equipment Availability Risk Level	Probability
As expected	0.80
Reasonable delay	0.15
Long delay	0.03
Total delay	0.02

The equipment availability risk was dismissed for Devil Canyon because of the available lead time in the schedule and the possibility of using the equipment from the Watana construction.

(k) Labor Availability/Strikes/Disputes

Labor availability was considered as the available local and non-local labor pool in the project vicinity. Any possible interruptions of such availability were considered as labor disputes or strikes. Since the majority of labor force are typical construction trades, the availability of labor is treated as a project demand rather than demand for individual construction activities. However, it should be noted that there are certain portions within each activity that require specific experience and skills (tunneling, pile driving, survey, iron work, welding, etc.). The availability of such skills is considered to be mainly affected by strikes and disputes rather than by initial lack of availability of the working force.

The Watana project labor demand is estimated to require a peak of 6200 men while the Devil Canyon project peak is 3500 men. Those two peaks occur five years apart and the peaks form a plateau of about four years each project (1988 to 1991 for Watana and 1994 to 1997 for Devil Canyon).

Since the construction force required by the Watana project exceeds the construction pool available in the Railbelt area, it appears that a serious labor availability risk may exist. The problem may be further complicated if other large size projects were scheduled during the period of the Watana peak demand. However, this comparison is based on available labor in 1981 rather than 1988. To establish a more realistic forecast of labor availability, information was obtained from the state of Alaska about projections of labor availability. In addition, investigation of the schedule for the Alaska gas line construction has been conducted to verify the possibility of any surplus labor available beyond the peak of that project.

A more recent preliminary investigation of labor availability for the Susitna project, performed by Frank Orth & Associates, indicates that the Watana project peak consists of:

	Total	Local	Non-Local
Laborers	3,689 (59%)	2,582	1,107
Semi-skilled	1,527 (26%)	1,058	569
Engineers & Administration	884 (15%)	398	486
	6,200 (100%)	4,038	2,172

It is estimated that labor demand in Alaska would reach 27,000 in 1985, 14,400 of which are required for the construction of the gas pipeline. This demand corresponds to a projected available supply of 15,500. Discussions with Frank Orth & Associates and major contractors in Alaska indicate that the large difference between supply and demand do not concern the contractors due to expected labor influx from the state of Washington. Such influx has been supplying the needs for labor in previous years, and was not considered in projecting the labor supply.

In view of construction schedules for the gas pipeline and the Susitna, Watana project, these schedules are sequential such that Watana peak follows the drop of labor demand for the gas line. Furthermore, the demand for the pipeline is about half that for Watana. This situation also occurs for Devil Canyon. It is very likely that labor force released from the gas pipeline would supply Watana, and labor force released from Watana would supply Devil Canyon. This fortunate situation is expected to ease the risk of labor availability.

Based on the above information, it was assumed that the planned labor requirement for the project can be satisfied. Therefore, the evaluation of this risk will consider the impacts due to labor strikes and disputes. Labor strikes or disputes are the results of an action by a few construction trades or by a general project strike. The impacts of such action are assessed for each construction activity.

Labor strikes and disputes were characterized as no strikes and/or disputes, minor, moderate and major strikes and/or delays. Activities where strikes and disputes could cause a potential risk impact were:

Watana

- Diversion Tunnels
- Cofferdams
- Main Dam
- Service Spillway Tunnel
- Penstocks
- Powerhouse
- Transformer Gallery
- Tailrace/Surge Chamber
- Turbine/Generator
- Test and Commissioning

Devil Canyon

- Main Dam
- Powerhouse
- Turbine/Generator
- Test and Commission

Each of these activities was assessed individually based on manpower necessary and critical nature of the subtasks. In general the risk probabilities were as follows; however, there was some variability due to the nature of each activities' labor situation.

Labor Strikes/Disputes Risk Level	(General) Probability
None	0.85
Minor	0.12
Moderate	0.02
Major	0.01

As a criterion response to all risks, a percent increase in the manpower level is estimated for each impact scenario within a risk when doing so will minimize the schedule delay. The results are evaluated against the labor supply and demand situation discussed above.

(1) Material Availability

This risk is concerned with the availability of material required for construction of the project components. R&M Consultants, Inc. have prepared a list of major item required for the project. These items are:

Material	Quantitites Watana	Quantitites Devil Canyon
Fill	76 Mcy	1.343 Mcy
Fuel	75 Mgal	17 Mgal
Explosives	20,000 T	3,000 T
Cement	350,000 T	650,000 T
Reinforcing steel	33,000 T	22,000 T
Rock bolts	12,500 T	3,000 T
Steel supports & liners	3,600 T	2,200 T
Mechanical, structural & Electrical equipment	15,000 T	13,500 T

Except for the fill and fuel, all material will be brought in from outside Alaska. The fill required is estimated by R&M to be largely available in the region of the project. Fuel sources are designated to be the refineries at Kenai and North Pole, Alaska, shipped from North Pole by rail or truck to the site, or piped to Anchorage from Kenai and then by rail or truck to the site. Therefore, neither the fill nor the fuel will be considered as risk for material availability.

Other materials may be considered to pose a possible risk depending on the quantities required and the ability of suppliers to meet the material demand. A major factor in determining the criticality of such demand is the schedule dictating the rate of demand. Three types of materials seem to be critical to obtain unless more than one supplier are selected. Those items are cement, reinforcement steel and rock bolts. The risk is not expected to cause added material quantitites or manhours demand. The risk is mainly critical regarding the schedule due to slower rate of material availability. Since the materials are required for a number of activities, it is not possible to clearly define which activity is more affected than the other. This situation definitely requires careful construction planning to distribute the material such that minimum effect is experienced by the overall schedule. Therefore, this risk is best assessed by treating all activities requiring a certain type of material, scheduled for construction simultaneously, as one group.

The construction activities which are affected by critical material availability for both Watana and Devil Canyon are as follows:

Activity	Cement	Material Reinforcement	Rock Bolts
Main Dam	X	-	-
Main Spillway	X	X	X
Outlet Facilities	X	X	-
Intake	X	X	-
Penstocks	X	X	X
Powerhouse	X	X	X
Transformer Gallery	X	X	X
Tailrace/Surge Chamber	X	X	X

Material availability risk is assumed to affect schedule only. Examination of the schedule indicates that most of the activities considered to be affected by the material availability are not on the critical path and each has a float time sufficient to allow schedule delays. This means that it is possible to minimize and almost eliminate the risk by proper allocation of available material to critical activities.

The risk probabilities for material availability were as follows:

Material Availability Risk Level	Probability
No problems	0.75
Minor delays	0.15
Moderate delays	0.08
Substantial delays	0.02

(m) Equipment Breakdown

Construction of the Watana and Devil Canyon power facilities will involve large quantities of heavy construction equipment including wheeled and tracked earth moving vehicles, rock drilling and processing machinery, concrete batching and handling systems, construction, power generation plants, and a variety of small support equipment used in construction and machinery assembly.

Experience available from previous large hydroelectric plant construction and the Alaskan oil pipeline construction project will be brought to bear on Susitna construction, both in planning and execution. The Alaskan oil pipeline construction experience is especially appropriate as it established effects of Alaskan conditions on equipment logistical support, operating life, maintenance procedures, and repair times for a variety of equipment.

Construction equipment breakdown will therefore not be a source of significant schedule delay. Adequate critical spares will be stocked and a comprehensive maintenance and repair facility will insure that equipment down time is minimized. Those areas most susceptible to equipment breakdown are represented by operations involving fill rock and aggregate preparation, such as rock crushers and batching plants wherein only a few pieces of equipment are used. But with the opportunity to stockpile significant amounts of this material, disruptions in the flow of fill rock and aggregate should not be significant.

Construction of the main access and cofferdam and intake which do not require any specialized equipment, large amounts of graded rock, or concrete, were not deemed to represent a measurable risk. Impoundment obviously does not involve equipment and therefore was not evaluated. All other construction activities for both Watana and Devil Canyon were evaluated.

Schedule delays due to equipment breakdown cannot be measurably reduced through the addition of manpower. In those areas where additional manpower could be used (such as putting additional vehicles to work to make up for failed equipment), the schedule risks are already low. Schedule delays related to more specialized equipment breakdowns, where greater risk is present, are tied to the repair or replacement of equipment components. These tasks cannot be improved by additional manpower to minimize schedule delays.

In general, the level of equipment breakdown and probability was as follows. However, there was some variability due to the specific nature of the equipment used in each activity.

Equipment Breakdown Occurrence Risk Level	Probability
Minor breakdowns	0.94
Moderate breakdowns	0.055
Major breakdowns	0.005

(n) Material Deliveries

Construction of the Watana and Devil Canyon power facilities will require that large amounts of materials be delivered to the sites. The predominant volume and tonnage of materials will be obtained in the immediate site area, consisting of fill rock and aggregate for concrete structures. Considerable amounts of smaller but critical materials must also be brought to the sites over long distances and from a number of different suppliers.

Delivery and placement of materials in accordance with the construction sequence and schedule are important to the overall cost of the project. Risks associated with these deliveries were evaluated.

Delays in material deliveries will occur, in most instances, as a result of three sources of risk:

- Errors in the scheduling and logistics associated with procurement and shipment of materials to the site.
- Manufacturing or production difficulties which delay the readiness of materials for delivery in accordance with the schedule.
- Natural forces and accidents which impede the normal delivery process; i.e., bad weather, accidents, etc.

Access to the site from the port of Anchorage is via improved road or rail to the Gold Creek area, with a construction road providing final access to the site. Material delivery to Anchorage will be via ship or barge, with the port remaining in service throughout the year.

Within the construction activities listed, several represent little risk relative to material deliveries. In most instances these activities use site produced bulk quantities which will be stockpiled at site with sufficient inventory to cover interruptions in supply. Other activities utilize small quantities of materials which do not pose any delivery problems (specifically the equipment required for testing and commissioning).

Those activities for both Watana and Devil Canyon where delivery of material, including equipment, represents a risk are:

- Site Facilities
- Turbine/Generator
- Switchyard
- Transmission Lines

For these activities, the following risk levels and probabilities were assigned:

Material Delivery Risk Level	Probability
Minor problems	0.95
Moderate problems	0.04
Major problems	0.01

The effect of additional manpower on reducing schedule delays due to material deliveries is felt to be negligible. This is due to the fact that most delays, once they occur due to events, are primarily logistical. There is little that can be done in terms of direct labor to improve the logistical exercise.

(o) Weather

The risk to the project from extreme weather is based on two components: temperatures for winter construction season and precipitation for summer construction season. Both temperature and precipitation would affect both the Watana and Devil Canyon projects during outside construction activities of earthwork and concrete.

Activities that are generally confined underground and as the project nears completion are not as exposed to the weather risk. For temperatures down to 20°F, earthwork and concrete operations can continue without extensive special techniques. Precipitation of one inch or greater per day was considered a substantial amount and taken as the risk level where operations would have to be suspended because of extreme conditions.

Available climatological data from the Summit meteorological station for a year's time was used in the analysis.

The following risk level probabilities have been developed based on the occurrence of days with a temperature above 20°F and days with a temperature below 20°F between the months of April and October, and the occurrence of days with a precipitation less than 1 inch/day and days with a precipitation greater than or equal to 1 inch/day for the same period. In relation to temperature, for the months of April and October the days for the two occurrences have been averaged to retain the assumed 180 day period of predominantly good weather during the year. It is assumed that the project construction schedule has already taken into account the severe weather conditions during the remainder of the year. Both factors of temperature and precipitation have been weighted equally for the purposes of probability estimates.

Weather Conditions Risk Level	Probability
Minor weather problems (above 20°F and less than 1 inch per day of precipitation)	0.94
Major weather problems (below 20°F and greater than or equal to 1 inch per day of precipitation)	0.06

(p) Contractor Capability

Contractor capability risk is considered to be significant for those activities in the project which are either large in magnitude or complicated to perform. The impact of the risk may be in terms of schedule delays or cost overruns or both. The risk ranges from a contractor being unable to meet schedule requirements to a contractor who is unable to complete the job in which case a new contractor must take over. History has shown cases of capability problems with larger competent contractors on certain jobs. Thus, the fact of having a competent contractor does not necessarily eliminate the risk but tends to reduce it. On the other hand, a number of large projects have been completed in the state of Alaska, most of which did not indicate that the contractors had any difficulties meeting their obligations. It is assumed that during the bid and award process, this risk would be considered and bidders evaluated on their capability and performance along with other requirements.

In the present evaluation, it will be assumed that a risk exists due to contractors capabilities; however, the probability of such risk is somewhat low. The damage is expected in the form of schedule delays depending on the activities with an extreme delay in the case where a new contractor must be brought in and a cost damage in the form of direct cost added as percentage of the initial cost for the activity.

Activities where contractor capability could be a major factor are:

Watana

- Diversion Tunnels
- Main Dam
- Penstock
- Powerhouse
- Turbine/Generator
- Mechanical/ Electrical

Devil Canyon

- Main Dam
- Penstock
- Powerhouse
- Turbine/Generator
- Mechanical/Electrical

The risk level probabilities were assigned as follows, with some variance due to the nature of the activity.

Contractor Capability Risk Level	Probability
No problems	0.95
Minor problems	0.03
Moderate problems	0.015
Extreme problems	0.005

(q) Construction Quality Control

Construction quality control is part of construction projects and its importance is as control on each step of the project to eliminate difficulties for subsequent activities. With the development of the field of quality control, more qualified personnel are now available. The level and complexity of the control required depends on the activity performed.

This risk is considered to assume different levels of impact in terms of schedule delays and cost. Assessment of these levels is based on two factors: (1) the effectiveness of implementing the project quality control program; and (2) the quality of manufacturers' and constructors' product. The effect of the first factor depends on the stages of work at which a nonconformance is detected. An early detection is considered to limit the impact, while a late detection would result in possible rework of the major portion of an activity with effect on subsequent activities. On the other hand, poor quality would cause significant impact.

In establishing the risk probabilities for the considered activities, the occurrence of combinations between the extremes of the two factors is considered.

Not all activities are considered in evaluating the risk due to quality control. Two criteria were followed in selecting the activities: (1) the magnitude of the activity and (2) the complexity and susceptibility of the activity to construction nonconformances.

The activities which meet these requirements for both Watana and Devil Canyon are:

- Main Dam
- Penstock
- Powerhouse
- Turbine/Generator
- Test and Commission

Other activities are dismissed considering the ease of construction, the non-criticality in dimensional tolerances and the relatively low magnitude compared to the entire project.

In general, the construction quality control risk was categorized as:

Contractor Quality Control Risk Level	Probability
As expected	0.92
Lax quality control	0.075
Poor quality control	0.005

(r) Construction Accidents

Construction of the Susitna hydroelectric project involves the use of large, high powered equipment, explosives, and thousands of laborers performing hazardous operations. Accidents will therefore occur, resulting in personal injury, and project cost and schedule impacts.

Construction accidents can be viewed as stemming from three sources. They are:

(1) Equipment. Equipment accidents are defined as failure or mishandling of equipment which precipitates some accident occurrence during construction. The accident itself is the cause of subsequent project delays or cost impacts, with the equipment being the catalyst only. Dropping of concrete transport buckets, vehicle accidents, and power supply failures are examples.

(2) Structures. Structural accidents represent a risk due to failure of excavations, civil construction, or fabricated structures. Such accidents may include tunnel or shaft collapse due to rock irregularities, or failures in steel supports resulting from improper material selection.

(3) Personnel. Accidents resulting from human error are defined as personnel accidents. They represent some lapse in logic or procedures which may in turn produce damage to equipment and structures, as well as personal injuries. Excessive or incorrect blasting charge placement, failure to secure bolts, or incorrect welding are examples of personnel caused accidents.

Construction of the diversion tunnels, penstocks, powerhouses, surge manifolds, transformer tunnels, and tailrace tunnels are underground operations and are areas of high accident rates due to their general nature. These areas also represent operations where damage resulting from accidents will have to be repaired before normal construction can continue. Surface construction of civil works is not as measureably sensitive to accidents as underground construction.

Several activities in both the Watana and Devil Canyon construction sequences are impacted at an insignificant level by construction accidents. The methods developed for their construction consist of a multitude of independent subtasks which do not concentrate a risk on an individual basis. These activities include:

- Site facilities
- Cofferdams
- Main spillway
- Emergency spillway
- Mechanical/electrical system
- Impoundment

The remaining 13 activities are considered to contain some measurable accident risk to both projects.

Construction accidents are considered based on the number of active workers during each activity. In general the risk assessment used the following values:

Construction Accidents Risk Level	Probability
Minor accidents	0.94
Moderate accidents	0.05
Major accidents	0.01

(s) Construction Sabotage/Vandalism

Sabotage and vandalism are identified as important risk areas considered during construction at both Watana and Devil Canyon sites. The public and special interest resistance to the Susitna hydroelectric development, as with any major project, has been apparent from the project's inception. As the project proceeds, resistance will predictably become even greater and will take a variety of courses of impedence that will include sabotage and vandalism. These acts are separate in nature and are defined as follows:

Vandalism

Vandalism is defined as acts committed by individuals for malicious reasons and not associated with any organized effort. Most vandalism acts are committed without preplanning and are expected to result in limited damage or delays.

The probability of occurrence of vandalism will be linked to the number of people actively engaged in site construction activities during the course of the project. The impact of any damage which occurs will increase as the amount of sophisticated equipment brought to the site increases, primarily in the later stages of the project.

Sabotage

Sabotage is defined to be the act committed by organized groups or foreign enemy for economical, political, or military strategy reasons. The act of sabotage is expected to be of much lower probability than vandalism. However, it is anticipated to be more violent in nature and result in more extensive damage. Due to the reasons behind a sabotage attempt, the risk is considered to be independent of any particular season, but will most likely be a function of the project's stage of completion. This is due to the fact that the large civil works and structures constructed at the beginning of the project are not sensitive to tampering or small destructive forces. Mechanical and electrical equipment installations can, however, be substantially affected by minimal amounts of sabotage effort. Sabotage will therefore most likely occur in the initial phase of the project where political and media impact would be highest, and again in the late stages of the project where physical damage in terms of cost and schedule would be greatest. Contrary to vandalism, sabotage is committed by organized groups or enemies according to well defined and rehearsed plans which include contingencies and alternatives to assure success of the operation. The intent and plan of sabotage, usually, are a well kept secret making a counter action to prevent sabotage a difficult matter. The individuals involved are well trained and devoted to the success of their mission. Thus, based on the anticipated proficiency of the operation, normal security forces are not expected to deter or to be effective in preventing a sabotage.

Both sabotage and vandalism are expected to have a minimal impact on cost and schedule during the first four years of construction. During the next eight years, when manpower levels are highest and Watana becomes substantially completed, acts of vandalism and sabotage will have their greatest impact. As Watana becomes operational and Devil Canyon manpower levels decline in the later phases of construction, such acts will again be reduced.

Sabotage and vandalism are expected to measurably affect all Watana and Devil Canyon project construction activites, except those related to electrical and mechanical systems which consist of items with short lead times and easily replaceable components.

The assessment of construction sabotage/vandalism risk events can generally be characterized as follows:

Construction Sabotage/Vandalism Risk Level	Probability
Minor	0.96
Moderate	0.035
Major	0.005

(t) Estimate/Contract Variance

Risks addressed in the preceding paragraphs have been viewed in light of changes (increments or decrements) which might be introduced as a result of realizing relatively extreme conditions. A major flood, for example, can lead to a cost increase in a particular activity simply because some work in place might be destroyed or damaged, requiring the expenditure of time and money to restore conditions to their pre-flood status. In addition to the uncertainties introduced by extreme or unusual events, however, there remains a great deal of uncertainty associated with the "normal" cost of any given activity. In effect, then, it is necessary to regard the distribution of changes intoduced by unusual risk events as being imposed upon an underlying probability distribution associated with "normal" variations.

From a conceptual standpoint, these underyling "normal" variations may be thought of in terms of uncertainties surrounding the estimating process itself, bid preparation and bidding strategy and actual contract performance. Examples in the estimating and bidding process include:

- Errors and omissions in the quantities
- Design changes which occur after the feasibility level estimate
- Differences in material prices
- Differences in labor rates
- Current market conditions which reflect competition amongst contractors and the general state of the economy at the time this project is announced for bid
- The incompleteness of the contractor's understanding of the bidding documents
- The use by the contractor of economies of scale on materials usually as a result of quantity order discounts or material substitutions

- The contractor's use of specific construction methods and techniques

- The intention of the contractor to buy into the job by submitting a low bid but then being very change order conscious throughout the contract or alternatively for a contractor to submit a very responsive but high bid because he does not have the resources to do the job at that time and would not be able to complete the proposed project with his current workload.

Contract variance includes that period of time between the budget or contract award and completion of construction. Similarly it includes the cost and schedule implications of such things as:

- Design changes

- Design omissions

- Changed site conditions

- Delays resulting in lost time, increased costs that are not the result of contractor's performance

- Delays due to other contractors

- The material variance whch includes the effects of material price increases and/or the effects of material usage

- Construction cost escalation over and above the underlying inflation rate.

Most of the above items are neither explicity accounted for nor well documented in the literature. Thus, it is difficult to ascribe probabilities and cost values on an item by item basis. It is possible, on the other hand, to make use of historical data which is reasonably applicable to the estimate/contract variance risk as a whole. The data set used for this purpose includes information for 49 federal water resources projects completed prior to the passage of the National Environmental Policy Act (NEPA). Important observations about selection and use of this data include:

- The choice of pre-NEPA data allowed us to distinguish between "normal" estimate/contract variance experiences and those which may have occurred in recent years as a partial result of major regulatory requirements.

- The choice of federal projects was made since most major water resources development in the nation has been undertaken by the government.

- The data base relates actual costs to "initial" estimates. "Initial" estimates are those estimates presented to the Congress at the time that authorization is sought for project development. As will be seen in succeeding paragraphs, an equivalent "initial" estimate is available for the Susitna project.

- Because the price range for elements of the data base was most comparable to that for activity costs on Susitna, estimate/contract variance was applied at the activity level.

- Of the 49 projects in the data base, one extreme value was discarded because the reservoir storage volume for that project had changed by several hundred percent between "initial" estimate and project realization.

The "initial" estimate for Susitna was taken from that submitted by the Corps of Engineers in the 1979 report. This value provided a basis for locating the current project estimate on the scale of ratios of actual cost to "initial" estimate.

Figure 4.1 provides a histogram showing the frequency of various ratio intervals in the data base. The triangular distribution shown on the same figure is the one selected for application at the activity level.

The triangular distribution selected for setting the estimate/variance risk is purposely biased toward the upper end of the data base, thereby introducing some measure of conservatism into the analysis. The minimum value of 1.0 for ratio of actual cost to "initial" estimate suggests that we do not believe the project will under any normal circumstance be completed for less than the Corps estimate (after inflation adjustments are made to make comparisons in January 1982 dollars). We selected the mean of the data base as the most probable value and chose the maximum value at 2.79 (two standard deviations from the mean).

In terms of typical Susitna activity cost estimates, the distribution is equivalent to setting the minimum value at 67 percent of the Susitna activity cost estimate, the mode at 91.5 percent, and the maximum at 184 percent.

(u) Schedule Variance

The variation in a project schedule tends to be much tighter than that associated with cost variations. However, meeting a project schedule is important and controlling the variability is a major effort.

The variability in the project schedule could be the result of positive or negative effects from:

- Labor productivity
- Weather conditions
- Major change in scope
- Regulatory delays*
- Environmental delays*
- Labor strikes or disputes
- Equipment or material delivery
- Construction techniques
- Construction planning
- Control of contract interface

In addition to the above items which occur once construction is started, we are also interested in differences between the schedulers' estimate and the contractors' estimate.

The Susitna project, being a multi-billion dollar project built over 15 years or more in a remote northern climate, will be subject to many adverse situations which would tend to delay the project. Because of this, the project estimates for construction activity durations would attempt to conservatively account for these conditions.

In general, a project of this size may expect, at the most, a reduction in the schedule by 10-15 percent, or 1 to 2 years. At the other end, a maximum delay could be on the order of 20-30 percent, barring major project work stoppages for long periods of time.

Obviously, this would not apply for all activities equally and therefore we must distinguish between critical path activities (CPA'S) and non-critical path activities. Typical project schedule control uses a critical path network to control and minimize delays on CPA'S but also to keep track of the float, or reduction in float, of the non-CPA's. Due to this control, it is expected that any delays in CPA's which are not externally imposed but which will affect project completion will be minimized to the extent that the project delay should not exceed 20 percent.

On the other hand, improvements in the schedule are much more difficult to achieve. Schedule control will concentrate first on reducing any possibility for delays, second on maintaining the schedule as planned and third on getting ahead of schedule. After project management is satisfied that the project is on schedule, under control and foresee no delays, they will then concern themselves with improving the schedule. They will do this for the purpose of providing a margin or time cushion particularly at the start of an activity for unexpected delays later. They may also accelerate all work associated with CPA's as soon as possible and then, once

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* These potential schedule influences are addressed separately as regulatory/environmental risks.

underway, keep these activities on a "fast track." For example, material deliveries will be expedited, the work day will be lengthened, more men and equipment, if available, will be used if it is efficient to do so and key critical phases of a work activity will be accelerated in order to accelerate subsequent critical activities. However, most of this effort is for keeping the critical path on the planned schedule. Unless there are contractor incentives to complete ahead of schedule, the best expectation is a 10 percent schedule reduction.

Another factor to consider is that Susitna is really two independent projects which have their own "on-line" dates. Watana, scheduled to start in 1985 and be on-line at the end of 1993, is a 9 year project. Devil Canyon's on-line date can be varied as a function of forecasted requirements. Given that the Watana on-line date must be met if significant revenue losses are to be avoided, the schedule for Watana is crucial. While major delays at Watana could impact the Devil Canyon development because of resource competition, the precise date for on-line power production is less critical.

It is reasonable to say in general that a range of about -10 percent to +30 percent may exist at the activity level and that the most important schedule risks should be addressed for Watana itself rather than for the project as a whole.

The indicated range would not apply equally to all activities. The minimum-maximum range for each activity is given and discussed below.

(1) Main Access -10% to +30%
This activity would exhibit much variability since it involves all heavy civil work subject to weather conditions. With right conditions, could improve schedule.

(2) Site Facilities -10% to +10%
Not subject to a wide spread because the work consists of setting up camp facilities, plant equipment, etc., which is uncomplicated construction. Good chance for improvement.

(3) Diversion Tunnels -5% to +15%

(4) Cofferdams -5% to +15%
- A CPA with little room for improvement
- Outside, heavy civil work
- Labor intensive activity

(5) Main Dam -10% to +20%

(6) Saddle Dam -10% to +20%
- CPA
- Outside, heavy civil work
- Labor and material intensive activity

- Major effort in entire project will get priority resources and management control
- Will tax capabilities but room for schedule gains
- Degree of construction complexity is high.

(7) Main Spillway -10% to +15%

(8) Emergency Spillway -10% to +15%

(9) Outlet Facilities -10% to +15%

(10) Intake -10% to +15%
- Non CPA
- Outside, mostly above ground construction, heavy civil work
- Degree of construction complexity is mid to high.

(11) Penstocks -5% to +20%

(12) Powerhouse -10% to +15%

(13) Transformer Gallery -10% to +20%

(14) Tailrace/Surge Chamber
- CPA competing with main dam as CPA
- Extensive below ground construction
- Extensive heavy civil work but multi-discipline work in the powerhouse
- Multi-contract coordination and interface in powerhouse.

(15) Turbine/Generator -10% to +10%

(16) Mechanical/Electrical Systems -10% to +20%
- CPA
- Indoor work
- Highly dependent on major equipment delivery but would be expedited because of critical nature
- Specialized work skills requiring precision close tolerance specification
- Equal chance to improve or delay schedule but not by much.

(17) Switchyard -15% to +10%
- Non CPA
- Uncomplicated construction with good chance to improve schedule but lesser chance to be delayed
- Delivery of switchgear, breakers is only significant possibility for delay.

(18) Transmission Lines -5% to +20%
- Non CPA but a major effort which requires attention so that it is not a CPA

- Complexity of construction is low
- Subject to weather and other natural conditions
- Rugged terrain, poor to limited access would minimize the improvement.

(19) Impoundment -10% to +20%
- CPA dependent on main dam construction
- Subject to wide variation in completion because of high vs low streamflow.

(20) Test and Commission -10% to +10%
- CPA
- Comments similar to T/G and M/E Systems.

(v) Regulatory/Environmental

This risk addresses the possibilities that the Susitna project development schedule will be held up due to unforeseen delays in the regulatory path the project must follow. The risks to the project schedule in this category will reduce through time, due to the decrease in the number of hurdles which the project must pass. Since Watana and Devil Canyon would be licensed together, the pre-construction periods would be the same.

To discuss the elements of this risk, the project development will be divided into three periods: pre-construction, construction and pre-operation. Pre-construction risks would involve a delay to the project start due to the failure to receive the required permits and licenses on schedule. The failure could be caused at local, state, or federal level. The expectation of failure at the local level is not an issue as there is only one permit needed. The state permits being held up are also not as likely since there is slack time of over one year to remedy any conditions found unacceptable in the process. The most likely delay would be due to the FERC license, which is in the critical path to development. Delay in granting the license would be in direct relation to delay of the project.

A delay in the license, or ultimate failure to obtain the license could result from several factors: new information could be presented which had not been considered in the preliminary studies; submitted data could be judged insufficient; legal problems could result due to court suits by intervenors or project opponents; rule and regulation changes could be enacted which could send the project back several squares in the process. A total of 30 months has been scheduled for acquiring the FERC license. There is a possibility that this schedule could be compressed to as few as 18 months with the probability of getting the license increasing as the 30 month figure is approached. The long side of the schedule appears to have a lesser probability of happening than the short side, at this time.

Should the license be held up for more than 5 years, it is very possible that it would never be issued.

Once a license is issued, the probability of a delay due to this risk decreases dramatically. At that time, the regulatory problem would become one of meeting conditions of the permits. A possible delay in this area could result from an unforeseen environmental condition, such as the critical habitat of endangered species. In addition, there would be the risk of a major design change taking place requiring an additional regulatory review. An environmental find could probably be resolved in 6 months to 1 year. If not resolved in that time frame, it is possible that the project would not be built.

The effect of a design change (such as dam slope change or spillway modification) would be compounded by the time necessary to get regulatory approval. This time could be from 3 to 6 months.

Another risk at this stage is the possibility of changes, invalidating the permits in hand. This risk is much less than at the pre-construction stage as new regulatory laws are not usually retroactive.

At the end of construction there remains virtually no regulatory risk that the project would not proceed into operation. Unlike nuclear projects, there is no additional operating license needed. Although several state permits would be needed to begin operation, these are basically procedural permits which, given proper lead time in application, would not hold up commissioning.

Figure 4.2 provides an assumed distribution for potential delays during pre-construction and construction periods.

(w) Summary of Construction Risk Assessment

Tables 4.6 and 4.7 summarize the applicable activity-risk combinations for the Watana and Devil Canyon construction projects respectively. These activity risks were used in the computer aided risk analysis summarized in Section 5.

4.7 - Operation Risk Assessment and Definition

For this study, the transmission system has been considered in the following corridor segments:

- From the Watana and Devil Canyon dam sites to the connection with the intertie (five single-circuit lines);
- From Fairbanks to the northern terminus of the intertie via Healy (two single-circuit lines);
- From Anchorage to the southern terminus of the intertie via Willow (three single-circuit lines); and
- A submarine segment in the vicinity of Anchorage, crossing Knik Arm (three single-circuit lines).

Design Features

The transmission lines will be built on single-circuit towers (345 kV) proposed as Guyed Steel Pole "x" structures which have been chosen to provide aesthetics, reliability, constructability, maintainability, and resulting economics. Foundations have been developed for various geologic conditions: good soils (43 percent), wetlands and permafrost (50 percent), and bedrock (7 percent). Minor variations could be anticipated due to meteorological, geologic, and environmental requirements. Towers are 95 feet high with a span of 1400 feet. The towers in parallel lines are 100 feet apart. The corridor width including the right-of-way on either side is 300 feet for 2 lines, 400 feet for 3 lines, and 700 feet for 5 lines.

In the submarine crossing, the transmission lines are buried 8 feet below the sea floor of Knik Arm.

Risk Significance

The transmission system is likely to be subjected to the following risks which may damage the transmission towers and lines causing power outage in the Anchorage and/or Fairbanks areas:

- Flood
- Wind and ice
- Seismic events
- Lightning
- River scour (submarine crossing only)
- Anchor dragging (submarine crossing only)
- Airplane collisions
- Vandalism and sabotage

Before assessing impact of risks on the transmission system, it should be considered that the transmission towers have been designed with certain inherent features of safety and convenience such as:

- The tower foundations are simple yet adaptable to varying geologic conditions. The steel legs are flexible which provides a greater tolerance to differential movements which may be caused by frost heave and thaw settlement.

- Vital supports are not provided by small bolted members in lower sections. Therefore, minor vandalism cannot cause critical damage to the tower.

- Minimal potential tower area and strong material characteristics would minimize the damage due to loading from avalanche or flood debris.

- Structural replacement is relatively easy and economic as the towers can be erected in small sections of lightweight components with a maximum weight of 3000 pounds.

General Assumptions

The following assumptions have been made while assessing the Anchorage/Fairbanks power outage due to damage caused by various risks.

- Unlimited skilled crews are available to work simultaneously on several lines and several towers.
- Tower and line components have been stockpiled at strategic locations in the vicinity of Fairbanks, Healy, Willow, Anchorage, and both dam sites.
- The towers are accessible by helicopter.

(a) Flood

It is understood that the transmission system foundations are designed for a 20-year flood and therefore should be able to sustain the event with only negligible damages. A 100-year flood has been assumed to cause the maximum damage. The debris loading may cause substantial damage to foundations thus toppling the transmission towers. The probabilities are evaluated as follows:

Flood Risk Level	Probability
Small Flood (0 - 20 year event)	0.94
Medium Flood (20 - 100 year event)	0.05
Large Flood ($\geq$ 100 year event)	0.01

Since the transmission tower would be located at high elevations, the damage would be negligible in the Susitna Intertie. The Fairbanks Intertie would be most susceptible to flood damage because of the locations of towers in the Tanana River floodplains. Damages to the Anchorage intertie segment would be moderate. Damages are anticipated in the submarine intertie segment.

A maximum period of seven days is anticipated to replace toppled towers and restore the power outage. This allows four days for floods to recede, one day for foundation repair, and two days to re-erect the tower. For the Susitna River Basin only, the floods are assumed to recede in one day.

(b) Wind and Ice

The design criteria for the transmission lines with respect to the conditions of wind and ice are as follows: heavy loading (1/2-inch thick ice, 40 mph wind), extreme wind loading (no ice, 140 mph wind), and heavy ice (1 inch thick ice, no wind).

The extreme winds for a 100 year mean recurrence interval, as reported by the Arctic Environmental Information and Data Center (AEIDC), are 60 mph for the area including both dam sites and 100 mph for the areas in the vicinity of Anchorage and Fairbanks. These are relatively moderate winds and do not pose a serious risk to the transmission system.

Data do not exist on the annual number of freezing rain days which could potentially cause formation of ice on the transmission lines. However, the lines are designed for the loads imposed by a 1-inch thick layer of ice which should be adequate for the area.

It should be noted that in order to add another layer of 1/2 inch thick ice, an unlikely rainstorm with 1 to 36 inches of freezing rain would be required. Both Susitna and Fairbanks interties are likely to experience severe winters with greater probabilities of ice formation. The conditions at Anchorage are anticipated to be mild.

The probabilities of various risk levels are as follows:

Wind and Ice Risk Level	Probability
No effect	0.973
Ice $\geq$ 1" thick (100 years)	0.01
Wind $\geq$ 140 mph (150 years)	0.007
Ice $\geq$ 1/2" + Wind > 40 mph	0.01

A maximum period of two days is estimated to repair the damaged transmission lines. The towers are not expected to be damaged by the ice and/or wind conditions.

(c) Seismic Events

The transmission system is designed for a ground acceleration of 0.3 g. The system would undergo considerable damage if an earthquake causes greater values. The Anchorage intertie is located in an area which is more seismically active than those of Susitna and Fairbanks interties. No damage is anticipated in the submarine segment of the system.

The probabilities for various risk levels are:

Seismic Risk Level	Probability
Negligible ($\leq$ 0.30 g)	0.9966
Small (0.45 g)	0.0029
Medium (0.55 g)	0.0004
Large (>0.63 g)	0.0001

A maximum period of five days is estimated for repairing the damages caused by an earthquake which includes two days for foundation repair, two days for tower erection, and one day for mobilizing the crew and material.

(d) Lightning

The risk of lightning damaging the transmission system is a function of the number of lightning strokes striking the towers or lines on an annual basis. As the current from a strike will be mostly conducted to ground, the risk is posed only if the intensity of lightning caused melting.

Data from two sources have been considered: Isoheraumic maps which indicate density distribution of the number of thunderstorm days per year, and a count of annual strikes to ground in an area that includes the corridor route. This information is being gathered as a part of a forest fire prevention program managed by the U.S. Department of the Interior, Bureau of Land Management. In both instances, the specific data have been somewhat limited, since the program is still in its infancy.

A total of 1000 strikes are reported over a 30,000 square mile area during the lightning season of 120 days. The corridor area for which the risk analysis is being performed is approximately 20 square miles. Assuming that 20 percent strikes will actually hit the transmisssion system, and only 5 percent of these strikes will be sufficiently intense to cause appreciable damage to the towers or the lines, it is estimated that such event will take place once in 76 years.

The risk level probabilities are as follows:

Lightning Risk Level	Probability
No Lightning	0.987
Lightning Strikes	0.013

A maximum three day period is anticipated to repair and re-erect the towers.

(e) River Scour

River scour, which refers to the local lowering of a river bed below its average natural level, would be a significant risk to the submarine transmission segment. This can be caused by secondary currents which develop due to changes in the local direction of flow. The conservative design criteria of burying the cables at least 8 feet below the sea bottom results in minimal bed exposure. However, the possibility of excessive scour does exist during spring snowmelt and ice breakup season.

The probabilities of the risk levels are as follows:

River Scour Risk Level	Probability
Negligible River Scour	0.99
Substantial River Scour (100 years)	0.01

A maximum of two days is estimated for repairing the transmission lines and replacing the cover materials.

(f) Anchor Dragging

The ship traffic in Knik Arm poses a risk whereby a passing ship may drag its anchor along the sea floor, possibly snag a transmission cable, and travel a distance which would cause breakage. Such instances have been recorded elsewhere in the past.

To estimate the probability of such an event is somewhat difficult on the basis of the available navigation information. A conjectural probability is assigned as 1 in 40 when a ship anchor will cause snapping of one transmission cable and 1 in 400 when two cables are involved.

The probabilities are as follows:

Anchor Dragging Risk Level	Probability
No damage due to dragging	0.9975
Damage due to dragging	0.0025

A maximum period of two days is estimated for the repair of the cables and replacement of the cover material.

(g) Airplane Collisions

Airplanes pose a substantial hazard of colliding with the transmission towers and lines. Collision events are more frequent during bad weather, such as fog, and are more likely to occur to transmission towers and lines since they are unequipped with aircraft warning lights. Both Fairbanks and Anchorage areas are characterized by a heavy air traffic which includes the commercial, military, and a large number of private airplanes.

The probabilities of an aircraft colliding with the transmission system are:

Airplane Collision Risk Level	Probability
No collision	0.95
Collision (1 in 20 year event)	0.05

A maximum period of three days is estimated to restore the power supply which includes one day to clear the plane wreckage and two days to re-erect the tower.

(h) Vandalism/Sabotage

While the risk of vandalism/sabotage is significant during construction, its potential for causing damage is somewhat reduced during operation.

Although the probability of vandalism is limited, it is more probable to occur in the suburbs of populated areas rather than out in the wilderness. Furthermore, it is very improbable to occur in the wilderness, or in the vicinity of the power plants since vandals at the plants would vandalize easily accessible equipment and machinery rather than exposed transmission lines.

Therefore, an act of vandalism is less likely to affect the Susitna intertie. Its probability is greater in the vicinity of Fairbanks and Anchorage where damage is mostly expected to affect the cables rather than the towers. While vandalism of the cables is possible by either shooting at or shorting out, the tower would require a sizable explosive charge to cause any damage. Explosives of this magnitude are not generally available to the public; therefore, the possibility of tower damage due to vandalism is considered remote.

Sabotage acts are expected to have a higher probability for areas which could result in a general outage for both Anchorage and Fairbanks. Furthermore, sabotage is expected to result in damages to both the towers and the cables causing extensive damage and extended outage compared to vandalism. The probability of sabotage is, therefore, substantially higher at the remote Susitna intertie than at the Anchorage and Fairbanks interties, both of which are closer to population centers. However, since sabotage is attributed to organized groups and enemy attacks, the probability of its occurrence tends to be very low. The risk levels and their probabilities are:

Vandalism/Sabotage Risk Level	Probability
Negligible/Minor Vandalism	0.9920
Major Vandalism/Minor Sabotage	0.0079
Major Sabotage	0.0001

A maximum estimated outage period of 3 days includes one day for foundation repair and two days for tower erection. In the case of the submarine crossing, a two-day period is estimated to excavate, repair, and cover the damaged cable.

(i) Summary of Operation Risk Assessment

Table 4.8 summarizes the applicable risks and affected transmission line segments. Note the column "Relationship of Number of Affected Lines." To deal with the case where a single risk event could cause damage to parallel lines, a risk was termed "high" or "low" in relation to the probability of effect on multiple lines. For example; Flood and Seismic events would more than likely impact all transmission lines in an area. Therefore, the term "high" related the probability of one day loss from realizing a risk event to 1.75 days lost due to miltiple lines lost. Conversely, "low" relationship risk events such as lightning assigned values of one day outage for one line to 1.05 days outage for multiple lines lost.

Expressing risks in this manner concentrated the effort of estimating damage consequences for one line only rather than the multitude of "ifs" which would have to be addressed considering combinations of one, two and three lines.

TABLE 4.1: SUSITNA HYDROELECTRIC PROJECT CONSTRUCTION COST ESTIMATE

Activity	Percentage of Total Cost: Watana	Percentage of Total Cost: Devil Canyon
1 - Main Access	8.5%	--
2 - Site Facilities	15.1%	20.0%
3 - Diversion Tunnels	3.8%	3.0%
4 - Cofferdams	0.3%	0.3%
5 - Main Dam 1/		
5a - Excavation	11.8%	15.6%
5b - Fill I (or concrete)	11.0%	22.0%
5c - Fill II	11.8%	--
6 - Relict Channel (or Saddle Dam) 2/	3.6%	4.0%
7 - Main Spillway	3.6%	4.9%
8 - Emergency Spillway	3.1%	2.3%
9 - Outlet Facilities	1.5%	0.9%
10 - Intake	3.6%	2.8%
11 - Penstocks	2.0%	2.1%
12 - Powerhouse	2.6%	4.2%
13 - Transformer Gallery	0.3%	0.3%
14 - Tailrace/Surge Chamber	1.1%	3.3%
15 - Turbine/Generator	2.3%	3.6%
16 - Mechanical/Electrical Systems	1.2%	1.5%
17 - Switchyard	0.4%	1.4%
18 - Transmission Lines	12.4%	7.8%
19 - Impoundment	--	--
20 - Test and Commission	--	--
Total	100.0%	100.0%

1/ Main dam is broken down into 3 activities for Watana and 2 for Devil Canyon.

2/ Activity 6 refers to Relict Channel for Watana and Saddle Dam for Devil Canyon.

TABLE 4.2: CONSTRUCTION ACTIVITY DURATION ESTIMATE

Activity	Duration in Months Watana	Devil Canyon
1 - Main Access	34	--
2 - Site Facilities	34	47
3 - Diversion Tunnels	22	22
4 - Cofferdams	10	9
5 - Main Dam 1/		
5a - Excavation	30	30
5b - Fill I (or concrete)	28	28
5c - Fill II	30	--
6 - Relict Channel (or Saddle Dam) 2/	31	32
7 - Main Spillway	54	45
8 - Emergency Spillway	31	32
9 - Outlet Facilities	34	18
10 - Intake	42	45
11 - Penstocks	42	29
12 - Powerhouse	69	69
13 - Transformer Gallery	24	18
14 - Tailrace/Surge Chamber	36	34
15 - Turbine/Generator	46	34
16 - Mechanical/Electrical Systems	34	27
17 - Switchyard	40	34
18 - Transmission Lines	42	34
19 - Impoundment	41	18
20 - Test and Commission	21	12

1/ Main Dam is broken down into 3 activities for Watana and 2 for Devil Canyon.

2/ Activity 6 refers to Relict Channel for Watana and Saddle Dam for Devil Canyon.

TABLE 4.3: PRELIMINARY RISK LIST - SUSITNA HYDROELECTRIC PROJECT

RISK	CONSTRUCTION	OPERATION
Natural		
Flood	X	X
River Scour	X	X
Ice	X	X
Ice Fog	-	X
Wind	-	X
Lightning	-	X
Seismic	-	X
Slope Stability	X	X
Temperature Extremes	X	X
Snow/Drift	X	X
Permafrost Deterioration	-	X
Geologic Conditions	X	X
Low Streamflow	X	-
Extreme Precipitation	X	X
Design Controlled		
Seepage/Piping	X	-
Structural Geology	X	-
Grouting	X	-
Groundwater	X	-
Structural Stability	X	-
Hydrodynamic Loads	X	-
Reservoir Induced		-
Seismicity	X	X
Hydrualic Loads	X	-
Erosion	X	-
Construction Cost and Schedule Risks		
Resource Competition:		-
- equipment availability	X	-
- labor availability	X	-
- material availability	X	-
Labor Disputes/Strikes	X	-
Labor Turnover Rate	X	-
Labor Rate Escalation	X	-
Equipment Breakdown	X	-
Equipment Cost Escalation	X	-
Material Cost Escalation	X	-
Maintenance Pers. Avail	-	X
Maintenance Parts Avail	-	X
Material Deliveries	X	-
Weather	X	-

TABLE 4.3 (Cont'd)

RISK	CONSTRUCTION	OPERATION
Human Related Risks		
Contractor Capability	X	-
Contractor Workmanship	X	-
Construction Accidents	X	-
Operation Accidents	-	X
Construction Sabotage	X	-
Operation Sabotage	-	X
Construction Vandalism	X	-
Operation Vandalism	-	X
Design Control	X	-
Construction Quality Control	X	-
Misoperation	-	X
Aircraft Collision	-	X
Anchor Dragging	-	X
Institutional/Economic/Political Risks		
Funds Delayed	X	-
Regulatory/Licensing Delay	X	-
Intervention (Public, Gov. Client)	X	-
Environmental Issues	X	-

TABLE 4.4: CONSTRUCTION RISK LIST

Natural Risks

1 - Flood
2 - Ice
3 - Wind
4 - Seismic Events
5 - Permafrost Deterioration
6 - Geologic Conditions
7 - Low Streamflow

Design Controlled Risks

8 - Seepage/Piping/Erosion
9 - Ground Water

Construction Cost and Schedule Risks

10 - Equipment Availability
11 - Labor Availability/Strikes/Disputes
12 - Material Availability
13 - Equipment Breakdown
14 - Material Deliveries
15 - Weather

Human Related Risks

16 - Contractor Capability
17 - Construction Quality Control
18 - Construction Accidents
19 - Construction Sabotage/Vandalism

Special Risks

20 - Estimate/Contract Variance
21 - Schedule Variance
22 - Regulatory/Environmental Delay

TABLE 4.5: TRANSMISSION SYSTEM OPERATION RISK LIST

Natural Risks

1 - Flood
2 - Wind, Ice, and Temperature
3 - Seismic Events and Slope Stability
4 - Lightning
5 - River Scour

Postulated Risks

6 - Anchor Dragging
7 - Aircraft Collision
8 - Vandalism/Sabotage

TABLE 4-6: WATANA
CONSTRUCTION ACTIVITY-RISKS

	MAIN ACCESS	SITE FACILITIES	DIV. TUNNELS	COFFER DAMS	MAIN DAM - EXCV.	MAIN DAM - FILL 1	MAIN DAM - FILL 2	MAIN SPILLWAY	EMERG. SPILLWAY	OUTLET FACILITIES	INTAKE	PENSTOCK	POWERHOUSE	TRANSFORMER GALLERY	TAILRACE-SURGE	TURBINE-GENERATOR	MECHANICAL-ELECTRICAL	SWITCHYARD	TRANSMISSION	IMPOUNDMENT	TEST/COMMISSION	
NATURAL RISKS																						
1 - FLOOD	X		X		X	X	X								X							
2 - ICE																						
3 - WIND																			X			
4 - SEISMIC	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
5 - PERMAFROST DETERIORATION	X				X						X								X			
6 - GEOLOGIC CONDITIONS	X		X		X			X	X	X	X		X									
7 - LOW STREAMFLOW																				X		
DESIGN CONTROLLED RISKS																						
8 - SEEPAGE/PIPING EROSION				X		X	X															
9 - GROUNDWATER	X		X		X								X									
CONSTRUCTION COST AND SCHEDULE RISKS																						
10 - EQUIPMENT AVAILABILITY			X																			
11 - LABOR/STRIKES/DISPUTES			X	X		X	X			X		X	X	X	X	X					X	
12 - MATERIAL AVAILABILITY						X	X	X		X	X	X	X	X	X							
13 - EQUIPMENT BREAKDOWN		X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	
14 - MATERIAL DELIVERIES		X														X		X	X			
15 - WEATHER	X	X		X	X	X	X	X	X	X	X							X	X			
HUMAN RELATED RISKS																						
16 - CONTRACTOR CAPABILITY			X			X	X					X	X			X	X					
17 - CONSTRUCTION QUALITY CONTROL						X	X					X	X			X					X	
18 - CONSTRUCTION ACCIDENTS	X		X		X	X	X			X	X	X	X	X	X	X		X	X		X	
19 - CONSTRUCTION SABOTAGE/VANDALISM	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	
SPECIAL RISKS																						
20 - ESTIMATE/CONTRACT VARIANCE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
TOTAL	9	6	11	6	10	12	12	7	6	9	8	9	11	7	8	9	4	7	9	2	6	168

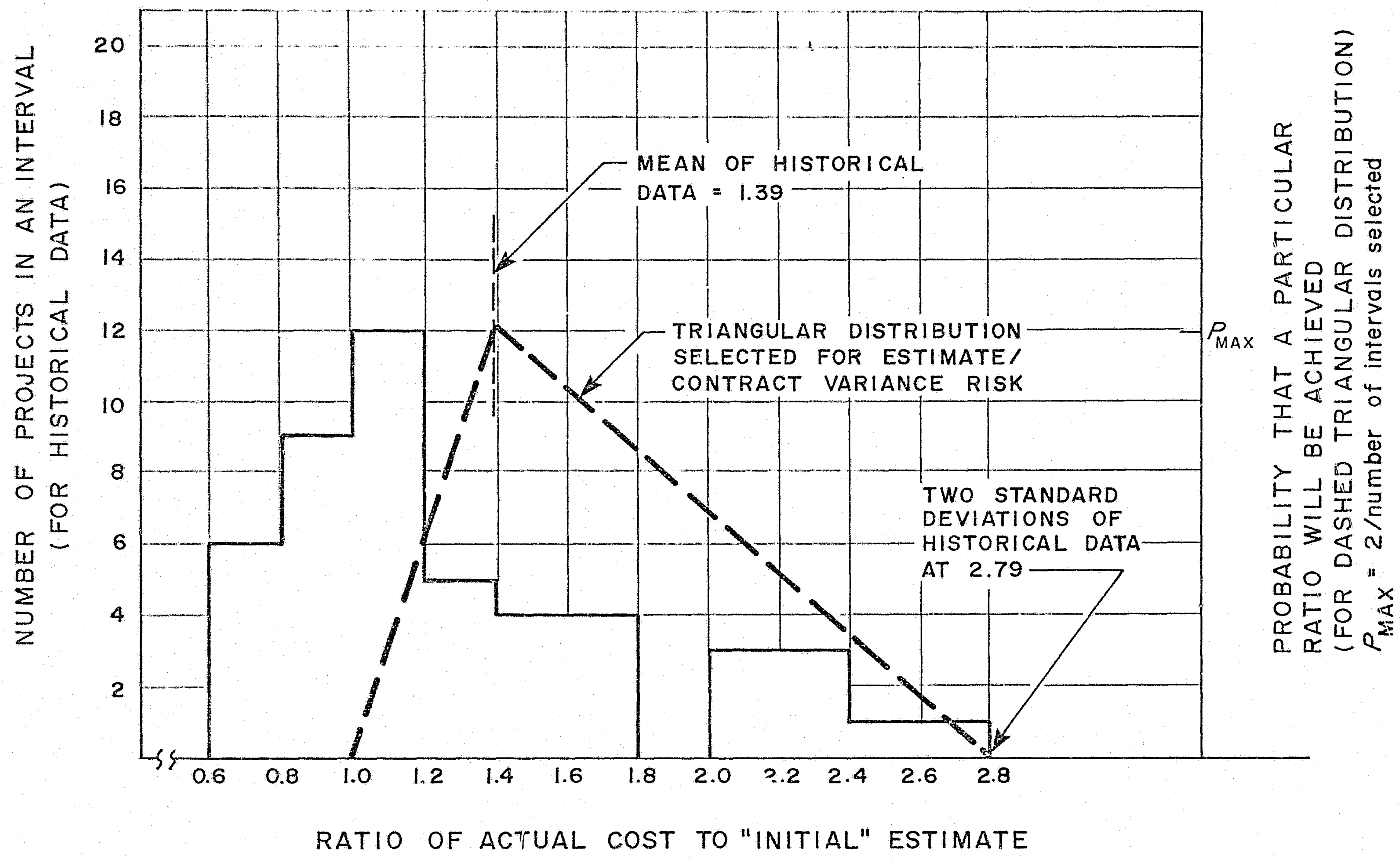
TABLE 4.7: DEVIL CANYON CONSTRUCTION ACTIVITY-RISKS

	SITE FACILITIES	DIVERSION TUNNELS	COFFER DAM	MAIN DAM - EXCAVATION	MAIN DAM - CONCRETE	SADDLE DAM	MAIN SPILLWAY	EMERGENCY SPILLWAY	OUTLET FACILITIES	INTAKE	PENSTOCK	POWERHOUSE	TRANSFORMER GALLERY	TAILRACE-SURGE	TURBINE/GENERATOR	MECHANICAL/ELECTRICAL	SWITCHYARD	TRANSMISSION	IMPOUNDMENT	TEST/COMMISSION	
NATURAL RISKS																					
1 - FLOOD		X		X	X				X					X							
2 - ICE																					
3 - WIND																					
4 - SEISMIC	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
5 - PERMAFROST DETERIORATION																					
6 - GEOLOGIC CONDITIONS		X		X		X	X			X		X		X							
7 - LOW STREAMFLOW																					
DESIGN CONTROLLED RISKS																					
8 - SEEPAGE/PIPING EROSION						X															
9 - GROUNDWATER		X		X								X		X							
CONSTRUCTION COST AND SCHEDULE RISKS																					
10 - EQUIPMENT AVAILABILITY																					
11 - LABOR/STRIKES/DISPUTES					X							X			X					X	
12 - MATERIAL AVAILABILITY					X	X	X		X	X	X	X	X	X							
13 - EQUIPMENT BREAKDOWN	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	
14 - MATERIAL DELIVERIES	X														X		X	X			
15 - WEATHER	X			X	X	X	X	X	X	X							X	X			
HUMAN RELATED RISKS																					
16 - CONTRACTOR CAPABILITY					X						X	X			X	X					
17 - CONSTRUCTION QUALITY CONTROL					X						X	X			X					X	
18 - CONSTRUCTION ACCIDENTS		X		X	X	X			X	X	X	X	X	X	X		X	X		X	
19 - CONSTRUCTION SABOTAGE/VANDALISM	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	
SPECIAL RISKS																					
20 - ESTIMATE/CONTRACT VARIANCE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
TOTAL	6	8	2	9	11	9	7	5	8	7	8	11	6	9	9	4	7	7	1	6	140

TABLE 4.8: TRANSMISSION SYSTEM OPERATION RISK MATRIX

Risk	Relationship of # of Affected Lines 1/	Affected Segments: Anchorage Intertie	Fairbanks Intertie	Susitna Intertie	Submarine Segment
Flood	High	Yes	Yes	Yes	No
Wind and Ice	High	Yes	Yes	Yes	No
Seismic Events	High	Yes	Yes	Yes	No
Lightning	Low	Yes	Yes	Yes	No
River Scour	High	No	No	No	Yes
Anchor Dragging	High	No	No	No	Yes
Airplane Collisions	Low	Yes	Yes	Yes	No
Vandalism/Sabotage	Low	Yes	Yes	Yes	No

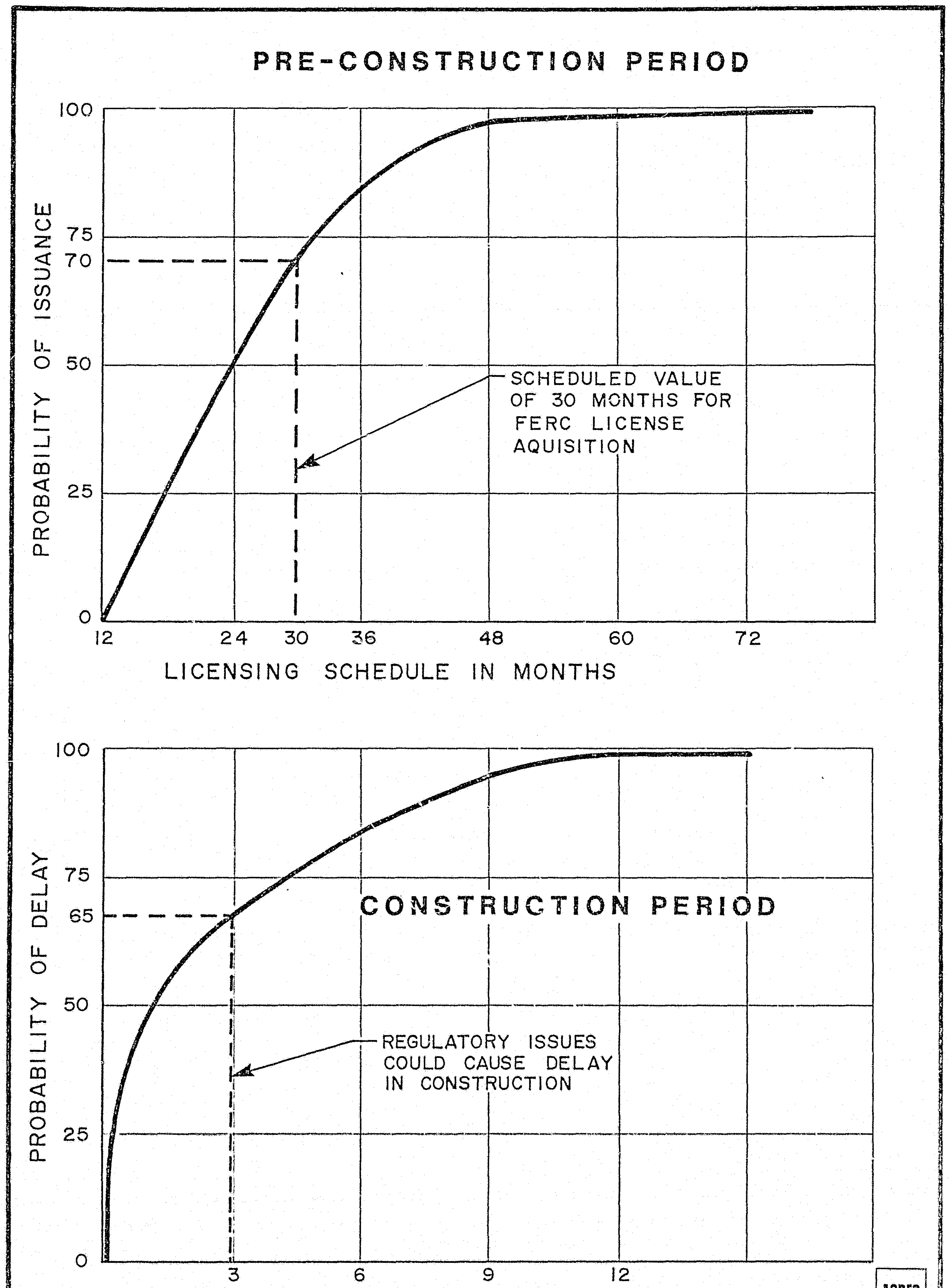
1/ High relationship between number of affected lines means there is a strong possibility of damage to more than one line should the risk be realized.



SELECTION OF ESTIMATE/CONTRACT VARIANCE DISTRIBUTION BASED ON HISTORICAL DATA

ACRES

FIGURE 4.1



PRE-CONSTRUCTION PERIOD
PROBABILITY OF ISSUANCE
100
75
70
50
25
0
12
24
30
36
48
60
72
LICENSING SCHEDULE IN MONTHS
SCHEDULED VALUE OF 30 MONTHS FOR FERC LICENSE AQUISITION
PROBABILITY OF DELAY
100
75
65
50
25
0
3
6
9
12
CONSTRUCTION DELAY IN MONTHS
CONSTRUCTION PERIOD
REGULATORY ISSUES COULD CAUSE DELAY IN CONSTRUCTION

FIGURE 4.2

SECTION 4 - LIST OF REFERENCES

(1) Design Criteria for Watana and Devil Canyon Development Second draft - October 1981

(2) External Review Board Mtg. #3, Information Package, October 6-8, 1981

(3) Development Selection Report Second Draft - June, 1981 and Appendices A through I Second Draft - July 1981

(4) Transmission Line Corridor Screening Closeout Report Final Draft - September 1981

(5) R&M Report, Subtask 2.10, Access Planning Study, September 1981

(6) Project Construction Requirements Scheduling, Subtask 2.10, Access Road, September 1981

(7) Commonwealth Report, Anchorage-Fairbanks Transmission Intertie Structure Study

(8) Construction Schedule and Capital Cost Estimate Documents

- Watana and Devil Canyon Construction Schedules, 4 full-size prints
- Preliminary Project Schedule (for Front End Activities) six 11 X 17 sheets
- CPM Analysis Listing for Watana and Devil Canyon 2 sheets each, 4 sheets total
- Preliminary Cost Estimate Format for FERC Code of Accounts without entires
- Updated Estimate, October 1981 three 8 1/2 x 11 pages
- Preliminary Manpower Requirements
- Watana and Devil Canyon Preliminary Estimate 11 x 17 Computer Printout

(9) Preliminary Design Layouts of Watana and Devil Canyon six 11 x 17 sheets

5 - FORMAL RISK ANALYSIS

5 - FORMAL RISK ANALYSIS

The methodology of the risk analysis has been defined and dissussed in terms of key concepts in Section 3. The technical evaluation and qualitative assessments of risks are presented in Section 4. This section explains how the methodology has been applied in the form of a detailed exposition of the calculation processes.

5.1 - Risks and Activity-Risks

Activity-risks for the construction analysis and risks for the operation analysis are the basic elements which drive the analysis. There are two different kinds of risks: those which may occur as one of a set of discrete events (for example, accident risks), and those which arise on a more or less continuous scale (for example, flood risks related to snowmelt). The continuous risks are reformulated into the discrete event structure by dividing the scale into suitable intervals and defining the risk as being associated with representative values within the intervals. This process varies in its detailed implementation from risk to risk.

There are various levels, then, at which a risk may arise, each level corresponding either to a distinct event or to a scale interval. The levels are defined so that they are jointly inclusive but mutually exclusive: they cover all possibilities but they do not overlap. Associated with each level of a risk is the probability $P_R(i)$ that this risk level will occur. Because the risk levels provide an inclusive set, we have:

$$\text{Sum over } i \text{ of } P_R(i) = 1,$$

for each activity-risk R. An example is shown in Table 5.1.

5.2 - Scenarios

When a risk or activity-risk arises, there may be a range of effects, responses and secondary risks. These are simplified to a set of scenarios which are consequent on the level of the risk and the particular activity. Scenarios are defined so that they are jointly inclusive but mutually exclusive.

Associated with each scenario is a set of conditional probabilities $P_S(j/i)$ of the scenario being realized, given that a particular level i of the risk arises. Because the scenarios are jointly inclusive, we have:

$$\text{Sum over } j \text{ of } P_S(j/i) = 1,$$

for each risk level i. An example of a scenario set and its matrix of conditional probabilities is shown in Table 5.2.

From the conditional probabilities $P_S(j/i)$ for scenarios and the probabilities $P_R(i)$ of risk levels, we calculate the unconditional probability $P_S(j)$ of scenario j arising, independent of the risk level:

$$P_S(j) = \text{Sum over i of } P_S(j/i)\ P_R(i).$$

We now find that:

$$\text{Sum over j of } P_S(j) = 1$$

for each scenario set S, as required. An example is shown in Table 5.3. The 0.63 entry is obtained by combining the 'small risk' level probability (0.7) and the 'no damage' probability given a 'small risk' level is realized (0.9), taking the product (0.7 X 0.9 = 0.63), and so on for each possible risk level/scenario combination.

5.3 - Consequences

If a scenario arises, its consequences are evaluated in terms of a set of criteria. For each criterion and each scenario, three values are provided: a minimum or optimistic estimate, a modal or most likely estimate, and a maximum or pessimistic estimate. These are interpreted as defining a distribution with either a triangular or a Beta form. For computation purposes, the distribution is reinterpreted as a corresponding rectangular histogram. For example, in the triangular distribution of Figure 5.1, the probability associated with the triangle in the interval 1.0 to 1.5 is redistributed as a rectangle in the interval 0.5 to 1.5, a slightly conservative assumption. Triangular distributions are used in the examples in this section for illustrative simplicity.

For calculation purposes, an interval base is defined for each criterion, and each distribution is converted to histogram form on this base (Figure 5.1). This provides a conditional consequence distribution, conditional on the scenario arising. Note that the sum of the probabilities over the intervals of a conditional consequence distribution is 1. This distribution is now scaled by multiplying by the unconditional probability $P_S(j)$ of the scenario arising, to form an unconditional consequence distribution for the scenario, independent of the risk level. An example is shown in Table 5.4: the conditional $P_S(j/i)$ was taken from Figure 5.1; the 0.68 is the 'no damage' $P_S(j)$ from Table 5.3.

For a particular activity-risk, scenarios are independent. The unconditional consequence distributions can be added by criterion intervals across scenarios, for each criterion, to form a combined consequence distribution for the scenario set associated with the particular activity-risk. An example is shown in Table 5.5, assuming 'minor' and 'major' criterion distributions of 2, 4 and 6, and a triangular distribution form. The first column of the Table 5.5 computation comes directly from the Table 5.4 result. The other columns are obtained using the procedure illustrated by Table 5.4 for 'minor' and 'major' scenarios.

5.4 - Combination Methods

The unconditional criterion distributions for the scenario sets are associated with particular activity-risks. Two combination methods are used: independent add and dependent add.

The independent add method for combining two distributions considers all possible pairings of criteria intervals, taking products of the probabilities within the intervals to obtain joint probabilities, and adding probabilities associated with common joint criteria intervals. An example is given in Table 5.6 for two risks: A and B. The result is illustrated in Figure 5.2.

The dependent add method for combining two distributions is most easily considered graphically. The first stage of the calculation considers the two distributions on the basis of 100 percent dependence: each criterion value in one distribution is added to the criterion value in the other distribution which occurs at the same percentile. In other words, the criterion value at the x-percentile of the result distribution is the sum of the two x-percentile criterion values from the distributions which are being combined. The process is illustrated in Figure 5.3, for the same source distributions A and B as were used in the independent add (0 percent A + B) example of Table 5.6.

The second stage of the dependent add method is a simple interpolation, at common percentiles, between the independent add (0 percent dependence) distribution (in cumulative form) and the 100 percent dependent add distribution calculated in the previous stage. The process is illustrated in Figure 5.4 where the dashed line represents 50 percent dependence and the single points represent 80 percent dependence.

5.5 - Combination Within Activities

Within a particular activity, activity-risks are combined using independent or dependent add to accumulate the total risk distribution for the activity. The risks are added in pairs beginning with the most dependent pair (or pairs) and then combining the next dependent pair or group of pairs. Figure 5.5 illustrates a risk dependency diagram for a single activity.

Levels of dependence between risks indicates the likelihood of incurring impacts from combination of risks. For example, in Figure 5.5, flood and seepage/piping/erosion are added at a relatively high dependence level. With an extreme flood, it is highly likely that problems with seepage and erosion will occur. However, seepage and erosion may occur without a flood, which means that flood and seepage are not totally dependent risks. Therefore, 70 percent dependence was used. When joining groups of risks together, the value assigned for dependence will reflect a representative dependence between the risks in the groups. If the risks or groups of risks are completely independent, zero percent is used. The values for dependency may vary from activity to activity based on the type of construction involved. For example, the dependence between equipment breakdown and weather will be different for an outside construction activity versus an activity which is partially or totally enclosed.

Within a particular activity, activity-risks are combined using the appropriate combination methods, to accumulate the total risk distribution for the activity. In the intermediate stages of this process, distributions are obtained which represent the effects of groups of risks on the activity.

5.6 - Combination Across Activities

The total risk distribution for activities can be combined in pairs, similar to combining risks within an activity, to accumulate an overall risk distribution for the project. Whereas the risk analysis methodology and software have been developed to process activity to activity dependence, the results presented in this report reflect only the dependence within an activity.

5.7 - Computer Software

The formal computation procedures discussed above easily lend themselves to computerization. The software adapted from Acres previous work in risk analysis with BP to meet the needs of this assessment is outlined below, referencing the applicable sections.

The program has two main functions, data handling and risk calculations. In its data handling mode, the program allows users to enter and remove data from the file structures, to change data, and to display it. This can be done at several levels, related to activity-risks, projects, or impact scenarios within a particular project. The calculation and plot modes produce probability distributions and generate plot files respectively.

The program is interactive, providing the user with a series of prompts or questions at each stage. The software to process the prompt messages and responses is part of the BP Risk Analysis package, and is proprietary to Acres and BP.

Since the program is interactive, a standard flow chart is not applicable; however, a simplified structure outline is shown in Figure 5.6.

5.8 - Program Verification

Each routine of the program was tested to check for proper data base handling and, as mentioned before, the program detects most data errors and illogical commands.

The calculation portion of the program was verified by using a number of simplified examples (similar to the one outlined earlier in this section) and hand computing the results, applying to the program and checking the results computed against those done by hand.

TABLE 5.1: RISK LEVELS AND PROBABILITIES, FOR EXAMPLE ACTIVITY-RISK R

Risk Level i	Probability $P_R(i)$
Small	0.7
Large	0.2
Enormous	0.1
	1.0

TABLE 5.2: CONDITIONAL PROBABILITY MATRIX FOR THE EXAMPLE ACTIVITY-RISK R

Scenario j	Conditional Probabilities $Ps(j/i)$		
	Risk Level i		
	Small	Large	Enormous
No Damage	0.9	0.2	0.1
Minor	0.1	0.6	0.3
Major	0.0	0.2	0.6
	1.0	1.0	1.0

TABLE 5.3: UNCONDITIONAL PROBABILITY CALCULATION FOR EXAMPLE ACTIVITY RISK R

Scenario j	$P_s(j/i)P_R(i)$	Unconditional Probability $P_S(j)$
No Damage	0.63 + 0.04 + 0.01 =	0.68
Minor	0.07 + 0.12 + 0.03 =	0.22
Major	0.00 + 0.04 + 0.06 =	0.10
		1.00

TABLE 5.4: CONDITIONAL AND UNCONDITIONAL CONSEQUENCE DISTRIBUTIONS

'No Damage' Scenario Criterion k: Min, Mode, Max = 1, 2, 3

Interval	Range	Consequence Distributions: Conditional $P_S(j/i)$		$P_S(j)$		Unconditional
0	0-0.5	0	X	0.68	=	0.000
1	0.5-1.5	.125	X	0.68	=	0.085
2	1.5-2.5	.75	X	0.68	=	0.510
3	2.5-3.5	.125	X	0.68	=	0.085
4	3.5-4.5	0	X	0.68	=	0.000
		1.0				0.680

TABLE 5.5: COMBINED CONSEQUENCE DISTRIBUTIONS

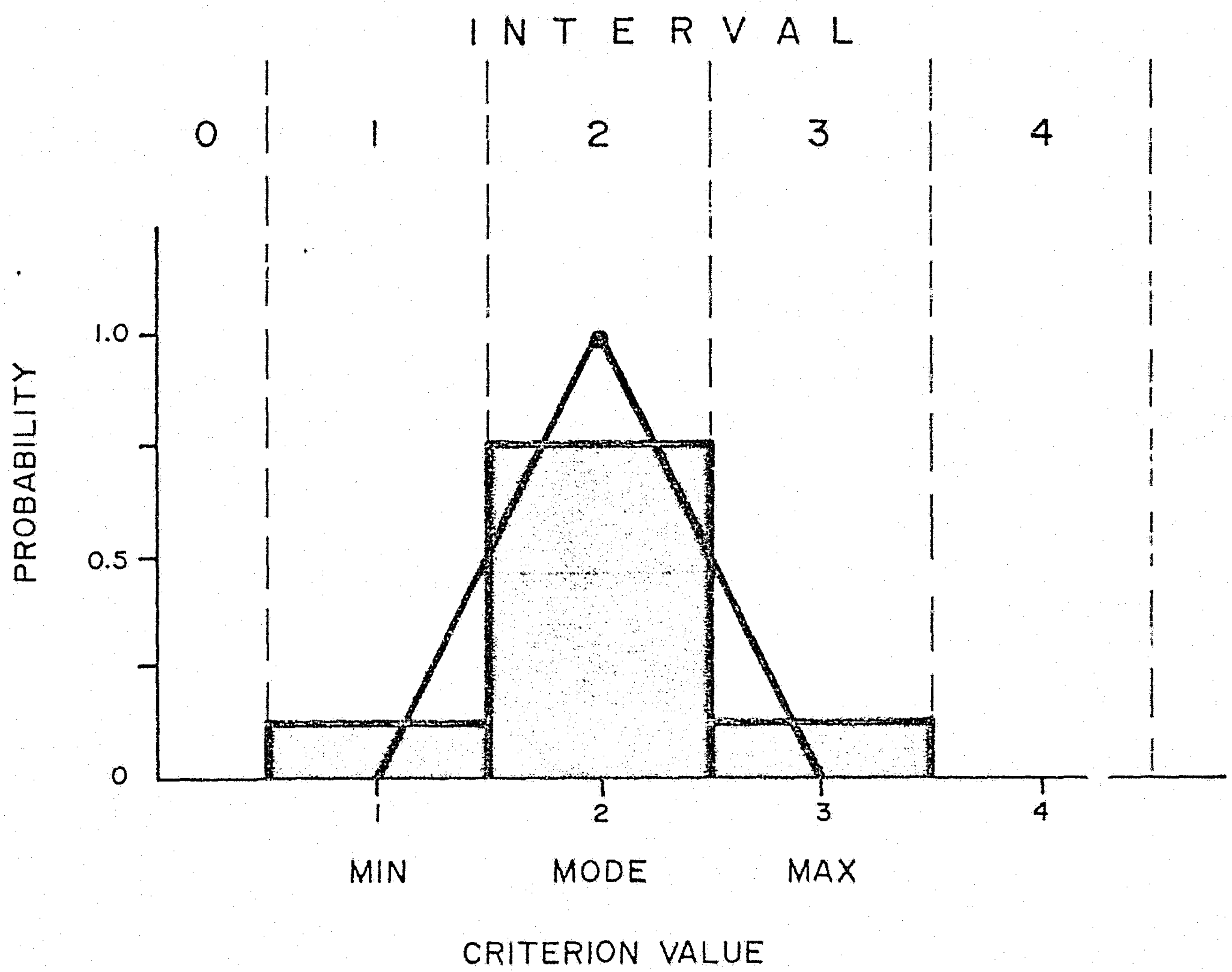
Interval	Range	Unconditional Consequence Distributions: No Damage (1,2,3)		Minor (2,4,6)		Major (2,4,6)		Combined
0	0-0.5	0.000	+	0.0000	+	0.0000	=	0.000
1	0.5-1.5	0.085	+	0.0000	+	0.0000	=	0.085
2	1.5-2.5	0.510	+	0.0069	+	0.0031	=	0.520
3	2.5-3.5	0.085	+	0.0550	+	0.0250	=	0.165
4	3.5-4.5	0.000	+	0.0962	+	0.0438	=	0.140
5	4.5-5.5	0.000	+	0.0550	+	0.0250	=	0.080
6	5.5-6.5	0.000	+	0.0069	+	0.0031	=	0.010
7	6.5-7.5	0.000	+	0.0000	+	0.0000	=	0.000
		0.680		0.2200		0.1000		1.000

TABLE 5.6: INDEPENDENT ADD COMBINATION METHOD

Interval	A	B	A&B			Cumulative
0	0	0			0	0
1	.1	0			0	0
2	.2	.3			0	0
3	.3	.3	(.1)(.3)	=	.03	.03
4	.2	.3	(.1)(.3)+(.2)(.3)	=	.09	.12
5	.2	.1	(.1)(.3)+(.2)(.3)+(.3)(.3)	=	.18	.30
6	0	0	(.1)(.1)+(.2)(.3)+(.3)(.3)+(.2)(.3)	=	.22	.52
7	0	0	(.2)(.1)+(.3)(.3)+(.2)(.3)+(.2)(.3)	=	.23	.75
8	0	0	(.3)(.1)+(.2)(.3)+(.2)(.3)	=	.15	.90
9	0	0	(.2)(.1)+(.2)(.3)	=	.08	.98
10	0	0	(.2)(.1)	=	.02	1.00
11	0	0			0	1.00
	1.0	1.0			1.0	

FOR DISTRIBUTION:

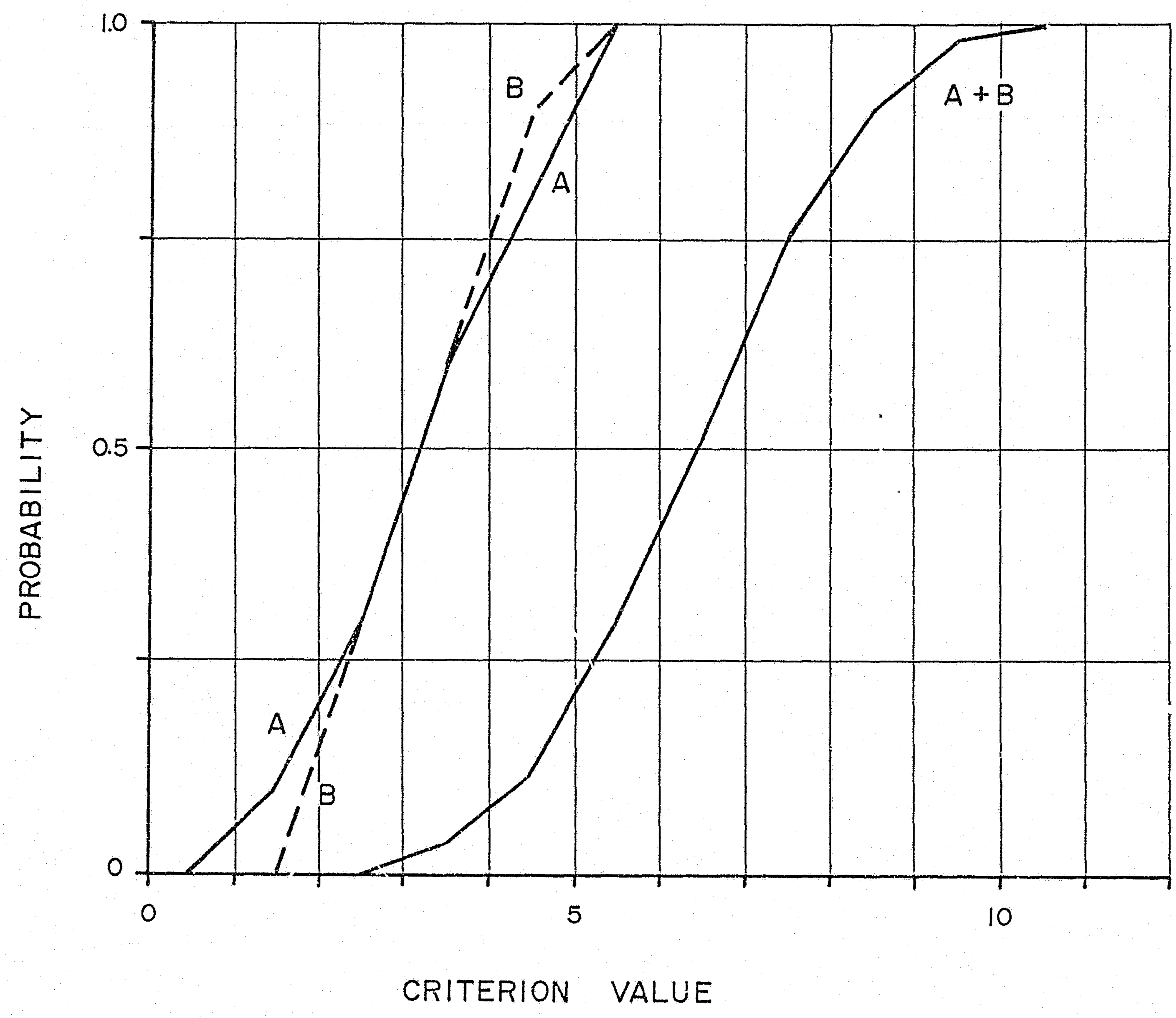
$(a,b,c) = (\text{min}, \text{mode}, \text{max}) = (1,2,3)$



NOTE: THE TRIANGLE NEED NOT BE SYMMETRIC, THE MIN, MODE AND MAX CAN ALL BE DIFFERENT. THE AREA WITHIN A HISTOGRAM "BOX" EQUALS THE AREA UNDER THE TRIANGLE IN AN INTERVAL

TRIANGULAR DISTRIBUTION
AND
CORRESPONDING HISTOGRAMS

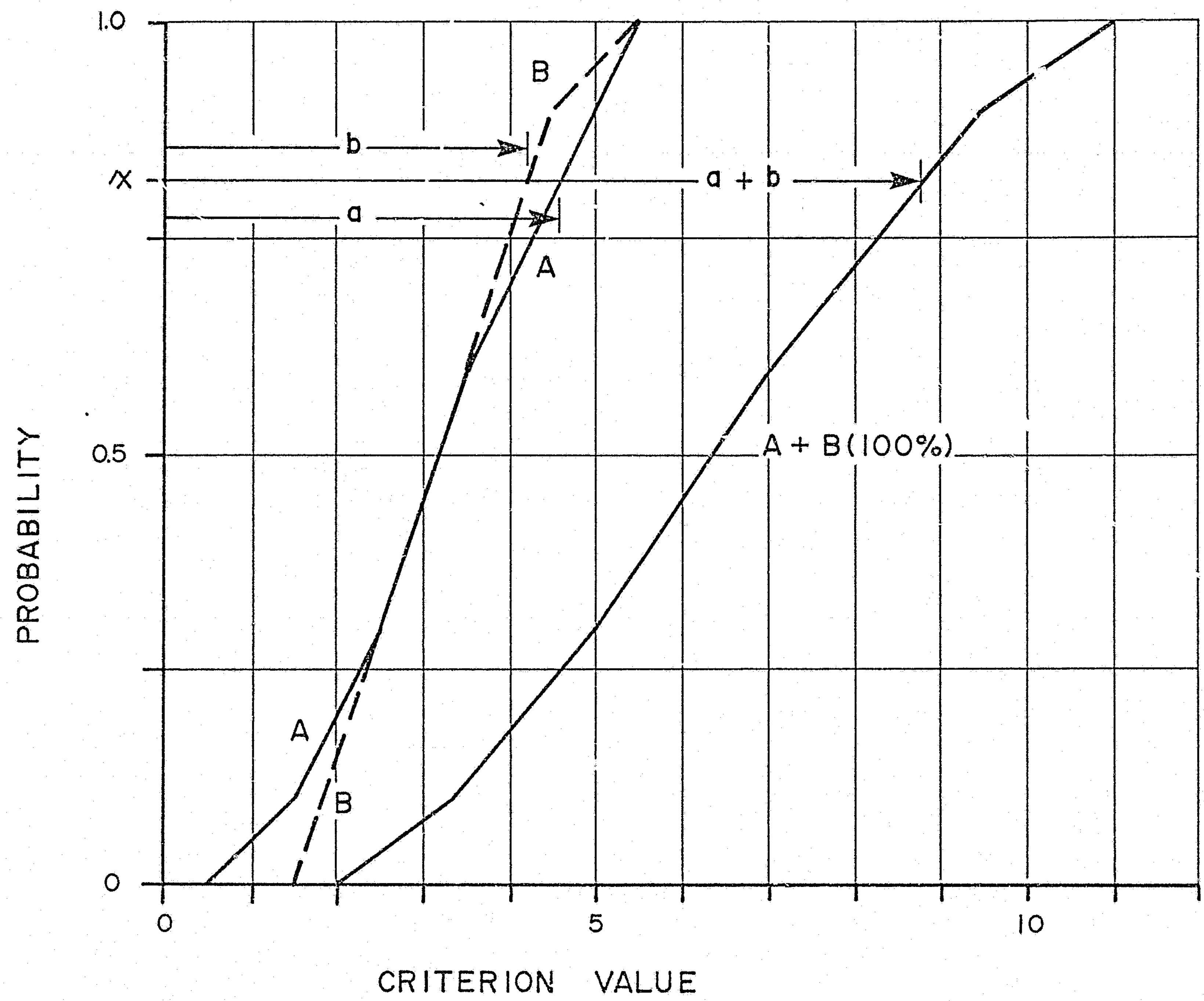
FIGURE 5.1 ACRES



INDEPENDENT ADD COMBINATION METHOD
(TABLE 5.6)

FIGURE 5.2

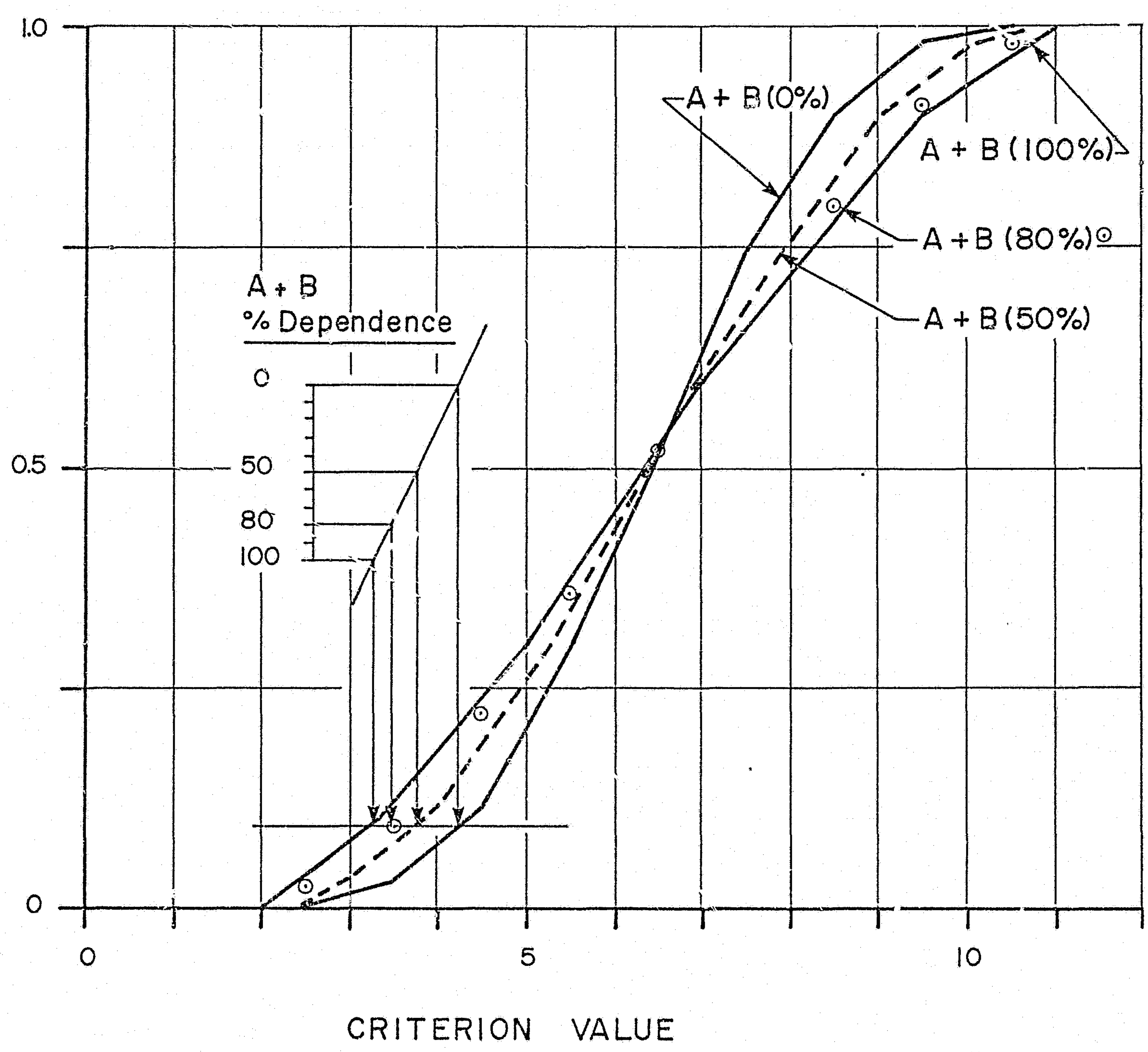
ACRES



DEPENDENT ADD COMBINATION METHOD FOR 100% DEPENDENCE

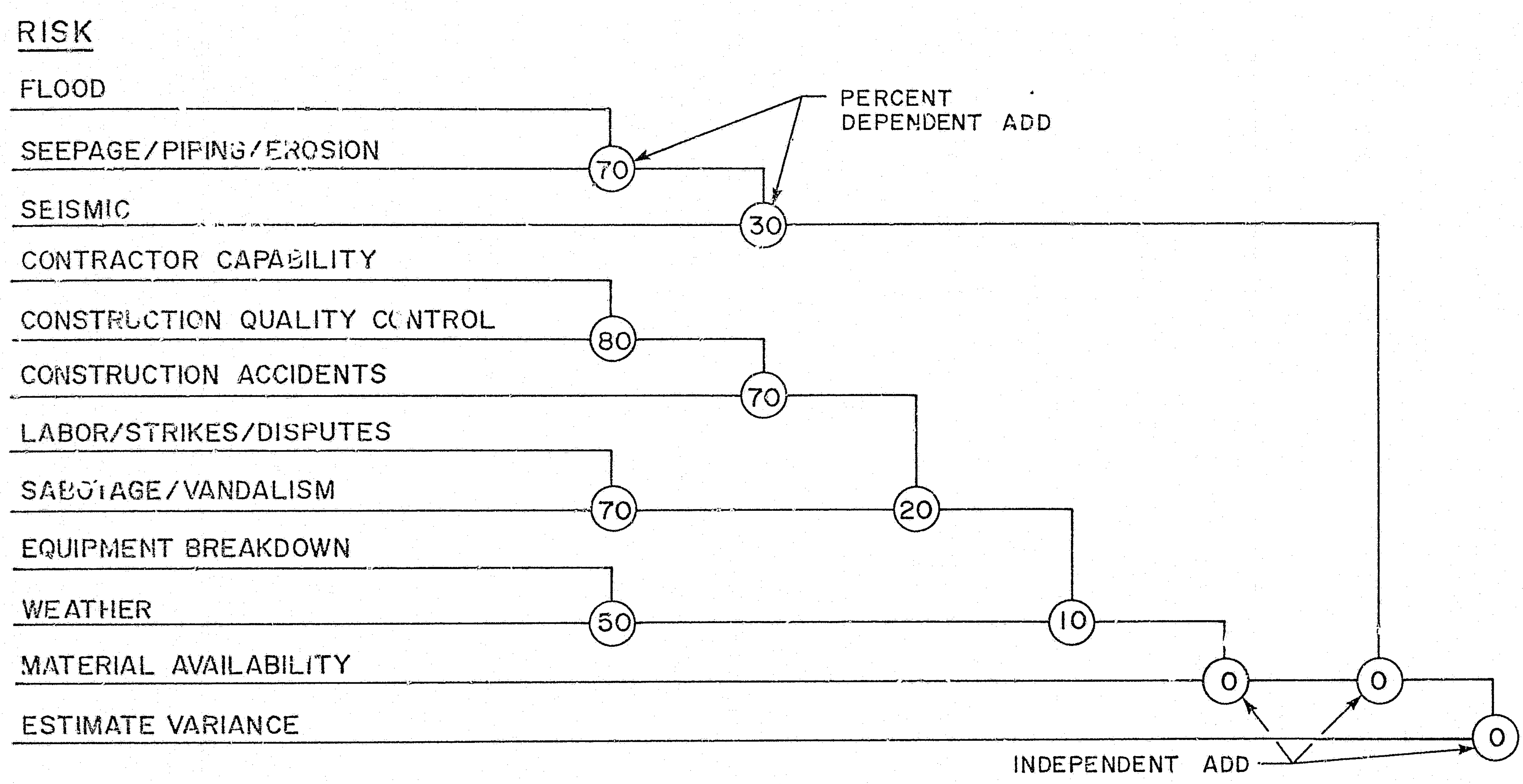
FIGURE 5.3

ACRES



DEPENDENT ADD COMBINATION METHOD FOR 50% DEPENDENCE (BROKEN LINE) AND 80% DEPENDENCE (SAMPLE POINTS ONLY)

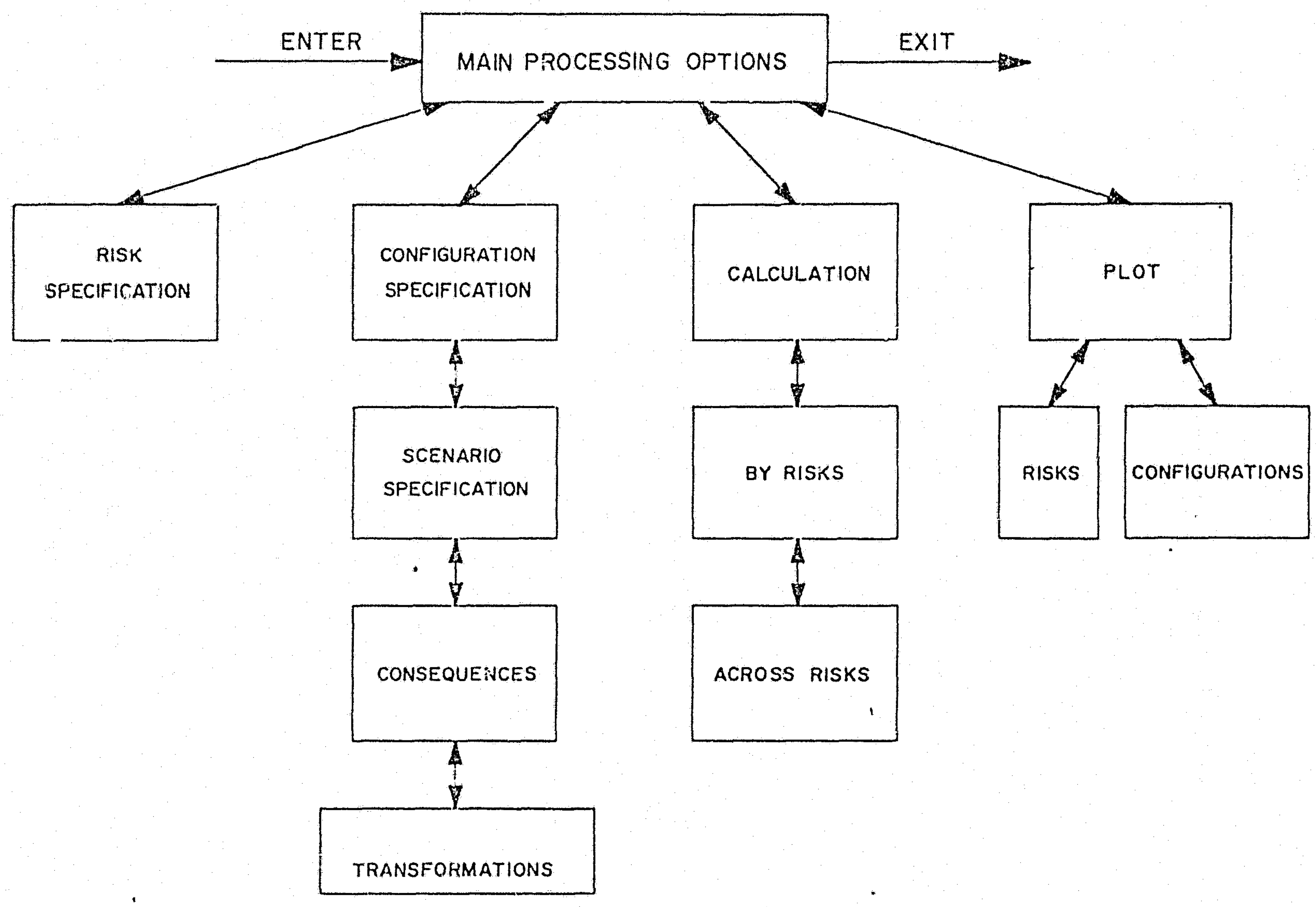
FIGURE 5.4 ACRES



EXAMPLE
RISK DEPENDENCY DIAGRAM

FIGURE 5.5

ACRES



SIMPLIFIED RISK ANALYSIS PROGRAM STRUCTURE

FIGURE 5.6

6 - RISK ASSESSMENT AND INTERPRETATION

6 - RISK ASSESSMENT AND INTERPRETATION

This section presents and interprets the results of the Susitna Risk Analysis. For ease of interpretation, cost implications are displayed in terms of ratios or percentages of particular "base" values. While absolute dollar values were used in the data base, a series of adjustments is necessary to convert them to costs which can be directly compared to the final project estimate as presented in the Feasibility Report (e.g., land costs and owner's cost were excluded from the risk analysis). The choice of a fractional scale avoids the extensive footnoting which would otherwise be required, and it allows for more direct and meaningful interpretation of results. Those analyses which consider time implications are presented in terms of days or months.

The Watana dam project is considered first because it is both the more costly of the two dams and its schedule is more critical in terms of economic and financial viability. Some disaggregation of probability distributions for Watana are discussed, primarily as the basis for considering the separate contributions of major risk categories in certain construction activities. The Devil Canyon dam project is next reviewed in risk terms.

Total project cost risk exposure is reviewed and comparisons are made with historical data for water resources projects.

Schedule risks are presented and interpreted only for Watana since there is considerably greater flexibility in the starting date for the Devil Canyon project. Finally, the potential exposure to outages (in Anchorage and Fairbanks) as a result of transmission line failures is addressed.

6.1 - Watana Cost Exposure

Figure 6.1 provides the cumulative distribution of total direct costs and their related non-exceedance probabilities as determined in the risk analysis. Annotations on Figure 6.1 are explained as follows:

(a) The simplest summary statistic for the Watana project cost is the expected value, indicated by the dashed line. The expected value is computed by multiplying each cost interval value by the probability that the particular cost interval will be realized and, summing the results. The expected value may be thought of as the cost which would be expected to occur on average if a very large number of projects of this type were constructed under identical conditions. The expected value of the cost of the Watana project is 90.25 percent of the project estimate.

(b) Point "A" on Figure 6.1 corresponds to the project estimate. As indicated by the distribution curve, the probability that the project will be constructed at a cost not to exceed the project estimate is about 73 percent.

(c) When sensitivity tests were made during the economic analysis of the Susitna project, a "low" capital cost value equal to about 83 percent of the project estimate was tested. Point "B" suggests that the probability of not exceeding this low value is about 46 percent.

(d) Sensitivity tests were also made for a "high" capital cost value equal to about 117 percent of the project estimate. The probability that the high value (Point "C") will not be exceeded is about 90 percent.

(e) In spite of the fact that there is a relatively high degree of confidence that the project estimate will be met, it is nonetheless true that there remains a small, but nonetheless important, chance of exposure to costs well above the "high" value which had been tested in the sensitivity analysis. The "tail" in the upper right hand corner of Figure 6.1 suggests that the 98 percent to 99 percent confidence level corresponds to capital costs which are as much as 140 percent of the project estimate.

(f) Taken as a whole, the distribution spans a relatively broad range of potential costs. This should be expected at the feasibility study stage since detailed design of the project has not yet been accomplished. If a decision is made to proceed with Watana and if a future risk analysis is conducted just prior to commencement of construction, the range of potential costs will probably be reduced considerably--reflecting the increased knowledge which will have been gained by that time.

6.2 - Watana Activity Cost Distributions

As expalined earlier in this report, each major configuration (e.g., the Watana project) was broken down into a set of activities (e.g., site facilities or main dam). Each appropriate identified risk was considered at the activity level. With one exception, the consequences of realizing a particular risk magnitude and a particular damage level were measured in terms of increments or decrements to the estimated cost of each activity. The single exception concerned the important estimating variance risk which had been evaluated on the basis of historical water resources cost experience. It was only in the case of this latter risk that potential total activity costs were used. This approach allowed us first to consider the contributions of various "unusual" risks (e.g., flood, seismic), treat their logical dependencies, and, as a final step, overlay the results on the estimating variance distribution. A certain degree of conservatism is inherent in this approach because it may reasonably be argued that the historical data base included incidences where "unusual" risks had been realized, thereby suggesting the possibility of double counting.

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Figure 6.2 reflects results for the "Site Facilities" activity at Watana. It displays cumulative non-exceedance probabilities for various percentages of activity costs for two major components of risk contribution. The left-hand curve is based upon only the estimate variance risk. The right-hand curve reflects the contribution of all risks. The shaded area between the two distributions provides a measure of the contribution of "unusual" risks to the total distribution. As might be expected, "unusual" risks tend to have a much greater influence at the upper end of the distribution--stemming from the fact that many of the "unusual" risks have low probabilities of occuring, but rather large consequences if they do occur.

Figure 6.3 and 6.4 provide similar distributions for other representative activities; diversion tunnels and main dam - Fill I.

In each case, the 100 percent activity cost estimate is found as the value of the activity in the project estimate plus contingency allowance plus construction cost escalation over and above the underlying inflation rate. The selection of this value at the activity level and at total project level is based upon the fact that the base case in the economic analysis used similarly determined project costs.

It is also useful to consider how "unusual" risks influence expected values at the activity level. The percentage contribution of "unusual" risks to total expected values for selected high cost activities is as follows:

Watana Activity	Percentage of Total Expected Value Contributed by Expected Value of All "Unusual" Risks
Main Access	5.4%
Site Facilities	8.9%
Diversion Tunnels	16.0%
Main Dam Excavation	6.7%
Main Dam Fill I (Lower)	8.1%
Main Dam Fill II (Upper)	6.6%
Main Spillway	3.8%
Intake	5.9%

6.3 - Devil Canyon - Probability Distributions

Figure 6.5 provides the cumulative probability distribution for Devil Canyon costs. Points A, B, and C on the curve correspond to those discussed above for Watana and are associated with probabilities of 74 percent, 47 percent, and 90 percent respectively for actual percentages of the project estimate being less than indicated values. Once again, a not insignificant long "tail" in the extreme upper right hand portion of the distribution provides a measure of the potential exposure to large overruns. The expected value of the actual cost is 91.5 percent of the project estimate.

6.4 - Total Project Distribution

Figure 6.6 combines the separate Watana and Devil Canyon projects, providing a cumulative distribution for the Susitna Hydroelectric Project as whole. Points A, B, and C now have associated probabilities of non-exceedance of 73 percent, 47 percent, and 90 percent respectively. If the project follows historical patterns, it may be expected that the wide range of possible values will narrow over time as detailed design and construction proceeds. A word of caution is important enough to deserve repetition at this point: the cost distributions are in every case based upon January 1982 dollars and they do not account for the effects of inflation. Nor do they include interest during construction or finance charges. Only the potential for extraordinary construction cost escalation (over and above inflation) has been taken into account. It follows that if the project is completed in the next several decades, the final "actual" cost will have to be adjusted to equivalent 1982 dollars if it is to be compared with risk analysis results as presented herein.

6.5 - Comparison with Available Data.

During the assessment of the important "estimating variance" risk, historical data for 49* Federal water resources projects completed prior to passage of NEPA were considered. While certain important limitations apply to the use of this data, it is nonetheless worthwhile to compare it with our Susitna Risk Analysis results. Recognizing that each of the historical projects differed from another in terms of cost, schedule, and complexity, we have once again chosen to normalize the data by displaying a cost ratio scale rather than an actual absolute cost value. Figure 6.7 offers a cumulative probability histogram for various cost ratios. In each case, the cost ratio reflects the actual project cost (after adjustment for inflation) divided by the "initial" estimated cost. As may be seen from the display, relatively large overruns have occurred in the past and they were almost inevitably the basis for widely publicized "finger pointing." Less well known, but particularly important, is the evidence that a substantial number of water resources projects have been accomplished for less than the originally estimated costs.

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* One project was removed from the data base because it was so drastically changed in scope from its original formulation that it biased all other data. Thus, figures presented in this section are derived from the remaining 48 projects.

In order to compare this information with the Susitna Risk Analysis results, it is necessary to determine the meaning of "initial" estimate in terms of the historical data. In each case, the "initial" estimate is the estimate presented to the Congress at the time that a request was made for project authorization. Thus, it would be inappropriate to regard the current Susitna estimate (as discussed in Chapter 16) as an "initial" estimate in the Federal sense. Fortunately, however, the Susitna project does have a long history of Federal involvement. Indeed, the Corps of Engineers provided a detailed "initial" estimate in 1975 as the basis for seeking authorization for important design activities. This "initial" estimate was further updated by a second "initial" estimate in 1979 after some additional exploratory work and further analysis were requested by the Office of Management and Budget. Inclusive of contingencies and excluding lands, the direct cost "initial" Corps of Engineers estimate (from the 1979 report) in January 1982 dollars for the Watana/Devil Canyon (thin arch dam) project was used as the denominator for display of possible Susitna cost ratios.

Figure 6.8 overlays the results of the Susitna Risk Analysis on the historical data. Note that the cost ratios differ on this display from those on Figure 6.6 because of the necessity to use the "initial" estimate for comparison purposes.

As may be seen from Figure 6.8, the Susitna Risk Analysis results reflect a more pessimistic expectation at low cost levels than the historical data would appear to indicate is reasonable. The degree of pessimism appears appropriate, however, for the following reasons:

(a) The pre-NEPA data base largely excludes cost implications of regulatory requirements. Our own assessment indicates that regulatory matters do impose some additional important cost burdens on post-NEPA projects. These have largely been accounted for in the project estimate, but some uncertainty must remain.

(b) The data base includes a variety of time intervals between the "initial" estimate and the actual realized cost. By disaggregating the data to include only those water resources projects reflecting 10 years or more between "initial" estimate and actual costs, a new histogram can be generated as shown on Figure 6.9. The Susitna results continue to appear pessimistic at the lower end in light of historical data, but the difference is seen to have diminished on this display. Some optimism is reflected for higher cost possibilites, but the Susitna estimate is well above the mean of the vlaues in the data set. The distribution also reflects a longer tail at the extreme upper end than the data set displays.

(c) The data base included water resources projects which are not directly comparable to Susitna. Removing such projects as canals, harbors, and locks permits generation of a third histogram for dams and reservoirs as shown on Figure 6.10. As may be seen from this display, the

Susitna Risk Analysis appears to offer an even more conservative expectation than the total data base had reflected.

In short, it appears reasonable to assert that the results of the risk analysis are consistent with historical data and, if any bias is evident, it is on the side of conservatism.

6.6 - Schedule Risks

At the same time that minimum, modal, and maximum cost values were estimated for each damage scenario in each risk-activity set, estimates were also made of similar values for potential schedule changes. As a result, schedule probability distributions were generated for each major activity. These individual distributions could not be combined in the same way as was accomplished on the cost side, however. Delays in certain activities can be tolerated with no expectation of change in total project schedule. Delays in other areas may bear a one-to-one relationship with total project delay.

A critical path network was prepared for the entire set of activities for each configuration. Individual probability distributions for critical activities were then combined to yield a distribution for the total project schedule.

Several critical paths were identified in the process since a long delay on a non-critical activity can, of course, place that activity on a new critical path. The raw schedule delay distribution was then considered in the context of a one year schedule contingency which had been built into the original estimate* and in light of regulatory delay risks. The resulting distributions are discussed and interpreted as follows:

(a) Figure 6.11 provides a cumulative probability distribution for months from the scheduled completion date for the Watana project. It reflects contributions except those posed by regulatory requirements. It is based upon a critical path through the main dam and it takes into account the one year schedule contingency. As may be read directly from the figure, the probability of completing the project ahead of schedule or on time is about 65 percent. There is only a 17 percent chance of completing the project a year early (i.e., in 1992).

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* It is important to note that with the exception of the "regulatory" and "estimate variance" risks, all criterion values were estimated as increments or decrements to the direct cost or schedule estimate. The assertion by the estimating team that a one year contingency was included in the schedule distribution was accounted for by shifting the raw probability distribution one year to a new center point.

(b) Figure 6.12 provides a similar distribution after regulatory risks are accounted for. Two components are included; (1) Prior to the start of construction, a license must be issued by the Federal Energy Regulatory Commission. There is a small chance (25 percent) that the license will be issued a year earlier than the current 30 month licensing schedule anticipates. The probability of meeting or bettering the 30 month estimate is about 72 percent and there is a 90 percent probability that not more than 38 months will be required (2) During the construction period, regulatory delays may be imposed as a result of various permitting requirements, injunctions, and the like. These delays yield only increases in schedule and range from a 50 percent probability of delays of a month or less to a 95 percent probability that regulatory delays during construction will not exceed 12 months.

As may be seen from Figure 6.12, the net effect of the regulatory risks is to broaden the range of possible values. At the lower end of the distribution, it will be noted that the chances of completing at least a year early have increased to nearly 40 percent--primarily because of the chance of getting a license early and therefore starting early. No significant change appears for the probability of meeting or bettering the schedule. A substantial effect is evident in the upper portion of the curve where the chances of long regulatory delays have pushed out the 95 percent confidence level to an expectation of no more than three years' delay--a significant change from the 12 to 13 months attributable to risks other than regulatory, as may be seen on Figure 6.11.

While similar distributions can be plotted for Devil Canyon, they are less meaningful since there is flexibility associated with its starting date.

6.7 - Transmission Line Risks

The separate risk analysis of the Susitna transmission system was conducted to determine the probability of significant power supply interruptions at the two major load centers in Anchorage and Fairbanks. The methodology was generally similar to that described in preceding paragraphs. Recognizing that the system is assumed to be in an operating mode, those risks which had applied only for construction in the preceding analysis (e.g., contractor capability) were eliminated from the risk list. Additions to the list were made to account for the potential effects of lightning, aircraft collisions, and anchor-dragging in Knik Arm (applicable to the submarine cable segment). Account was taken of redundancies designed into the system (e.g., a loss of one line in the three line system extending south toward Anchorage can be tolerated with no loss of energy delivery capability).

In addition, special attention was given to dependencies (e.g., an earthquake which causes the loss of two lines will very likely knock out the third. On the other hand, vandalism which causes an outage on one line is only infrequently expected to extend to all lines). Important assumptions included the availability of well-trained repair crews and equipment, and a reasonable supply of spare components.

The results of the analysis provide the cumulative probability of not exceeding a given number of days of reduced energy delivery capability. Figures 6.13 and 6.14 display this information for Anchorage and Fairbanks, respectively. Interpretations are as follows:

(a) In the particular case of Anchorage (Figure 6.13), it will first be noted that the probability scale includes only the extreme upper range of non-exceedance probabilities. The intersection of the distribution curves on the probability axis indicates that the probability of no lost energy delivery capability in a given year is 0.958 and of not having 50 percent reduction is 0.955. Beyond these points the curves rise sharply, indicating that outages beyond 5 days are extremely unlikely. The "expected" annual value of 0.06961 days for a total delivery loss may be compared with the "loss of load probability" of 0.1 (one day in 10 years) which had been used in the generation planning efforts in the economic studies. In short, the risk analysis confirms that the reliability of the transmission system for energy delivery to Anchorage is consistent with the requirements of the overall Railbelt generation system. The "expected" annual value of 0.09171 days for a 50 percent reduction in energy delivery appears to be similarly acceptable when compared to assumed loss of load probability.

(b) The cumulative probability distribution for Fairbanks (Figure 6.14) has a slightly different intercept on the probability axis and its shape is also slightly different from those for Anchorage. These differences stem from the facts that delivery to Fairbanks requires no submerged crossing and certain other risks (e.g., flood, temperature extremes) would be expected to have different probabilities for northern and southern segments of the system. In spite of the absolute differences, it may be seen from the display that the "expected" annual value of 0.08116 does not exceed the loss of load probability criterion of 0.1 day per year. No 50 percent loss for Fairbanks is shown since the loss of one of two lines causes no reduction in delivery capability. Two lines lost is, of course, a 100 percent loss.

(c) An analysis presented in Section 6.8 indicating what emergency response would be required in the event of a loss of energy delivery capability to each of the two major load centers. Clearly, the most severe problem would occur if a transmission loss occurred during the winter period since peak demand during the remainder of th year is e generally less than 70 percent of the peak during the late fall and winter months. Whereas Figures 6.13 and 6.14 reflect annual cumulative probability distributions for days lost, a distribution for the worst case winter period is different. Figure 6.15 provides winter outage distributions for Anchorage and Fairbanks. They were compiled by re-running the transmission system risk analysis exclusive of certain risks which would be a major threat only in non-winter periods. The following risks were considered to be inapplicable during late fall and winter months:

- Flood
- Scour caused by flood
- Lightning

As may be seen from Figure 6.15, the distribution for a total loss of Susitna energy deilveries to Anchorage during the late fall and winter indicates the following probabilities for indicated outage periods:

Annual Probability That Total Winter Outage Will Be:	Value
None	0.985
One day or less	0.998
Two days or less	0.999

The expected value is 0.01801 days.

Similarly, for Fairbanks, corresponding values are:

Annual Probability that total winter outage will be:	Value
None	0.980
One day or less	0.996
Two days or less	0.998

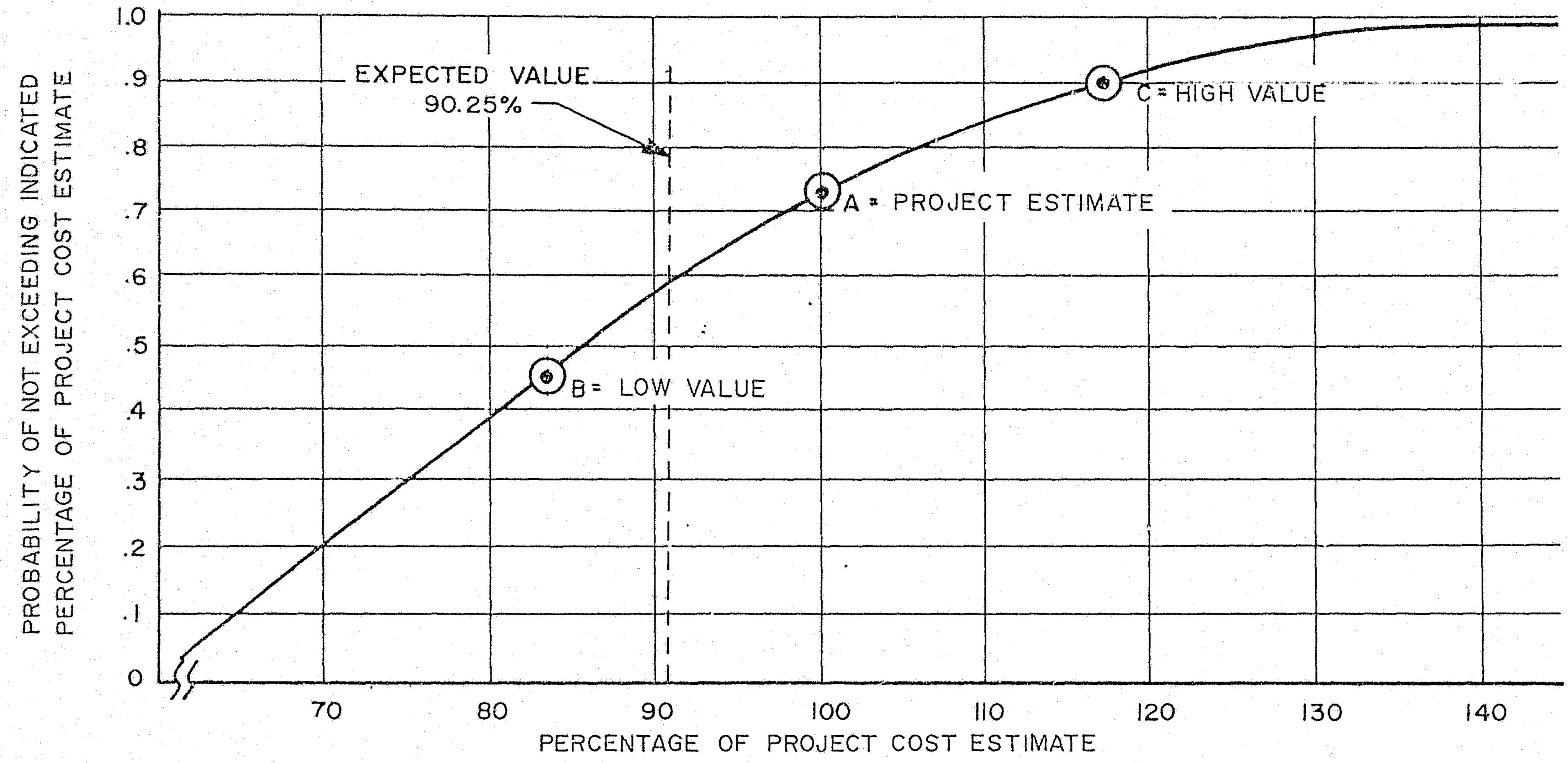
The expected value is .02067 days.

It is important to understand that the above results are based upon the analysis of an assumed mature transmission system. This is to say that the incidence of problems on any new major project tends to be greatest during an initial shakedown period, diminishing as the project achieves sustained operations. Our analysis indicates that the most critical period for having to sustain a major outage begins about 2000, peaking during the first decade of the 21st century. Since the system is expected to commence operation in 1993, it can reasonably be regarded as "mature" during the critical period. Assuming that some load growth will continue beyond 2010, Susitna energy as a percentage of total energy will gradually diminish and the relative impact of a transmission outage will be correspondingly reduced.

Risks that will significantly affect the performance and operation of the transmission system were assessed in terms of days of lost power in Anchorage and Fairbanks. The assessment of the emergency generation was made on the basis of these losses.

The assessment considers that if a risk is realized, the resulting consequences may cause the loss of Susitna generation. A set of responses is then required in order to assess the ability of the system or other generation facilities to provide this emergency power.

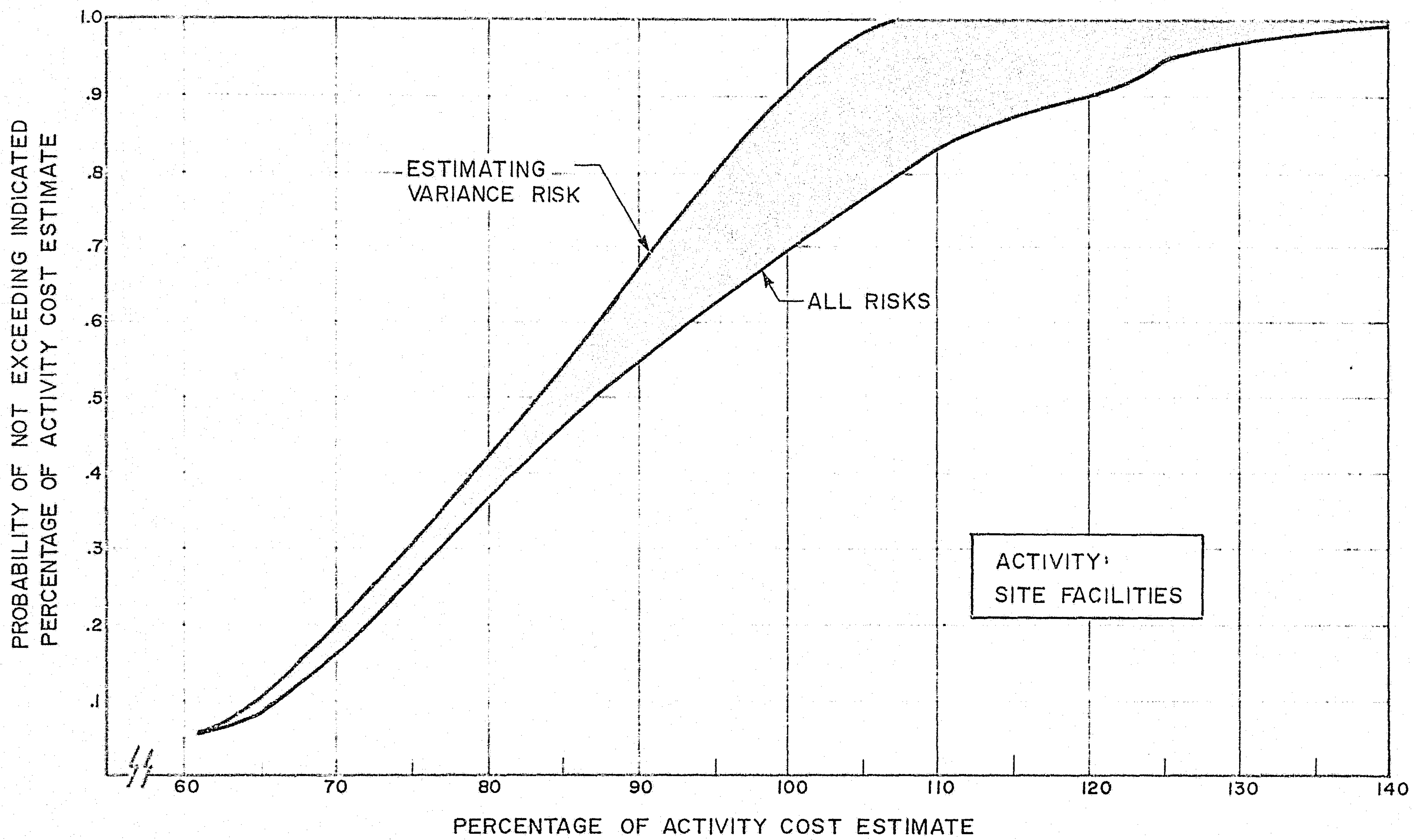
Appendix A presents the system's ability to respond to planned or forced outages based on plant operating experience; the impacts of power loss from Susitna; and responses to provide emergency power.



CUMULATIVE PROBABILITY DISTRIBUTION FOR WATANA COSTS

FIGURE 6.1

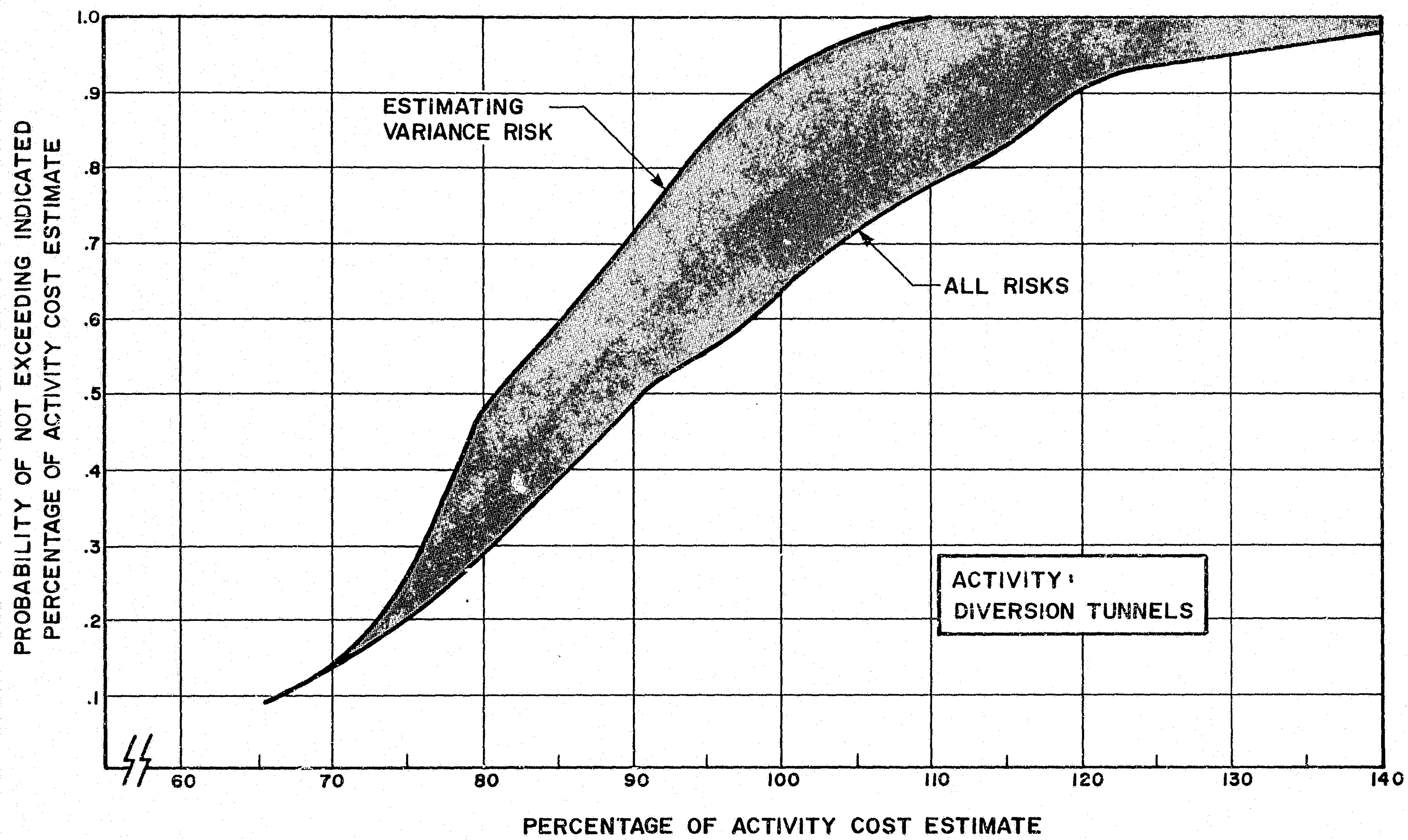
ACRES



CONTRIBUTION OF UNUSUAL RISKS AT THE ACTIVITY LEVEL FOR SITE FACILITIES

FIGURE 6.2

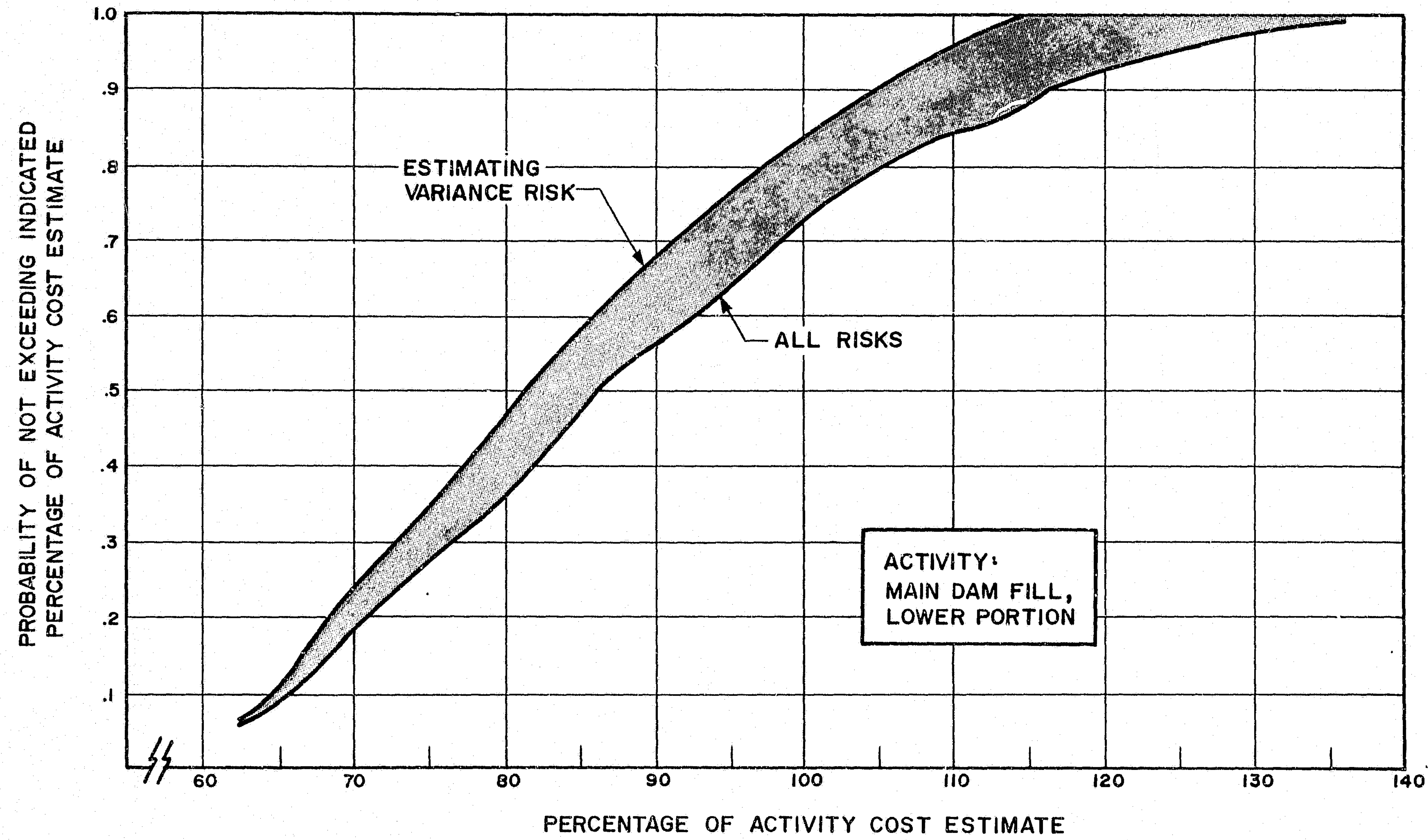
ACRES



CONTRIBUTION OF UNUSUAL RISKS AT THE ACTIVITY LEVEL FOR DIVERSION TUNNELS

FIGURE 6.3

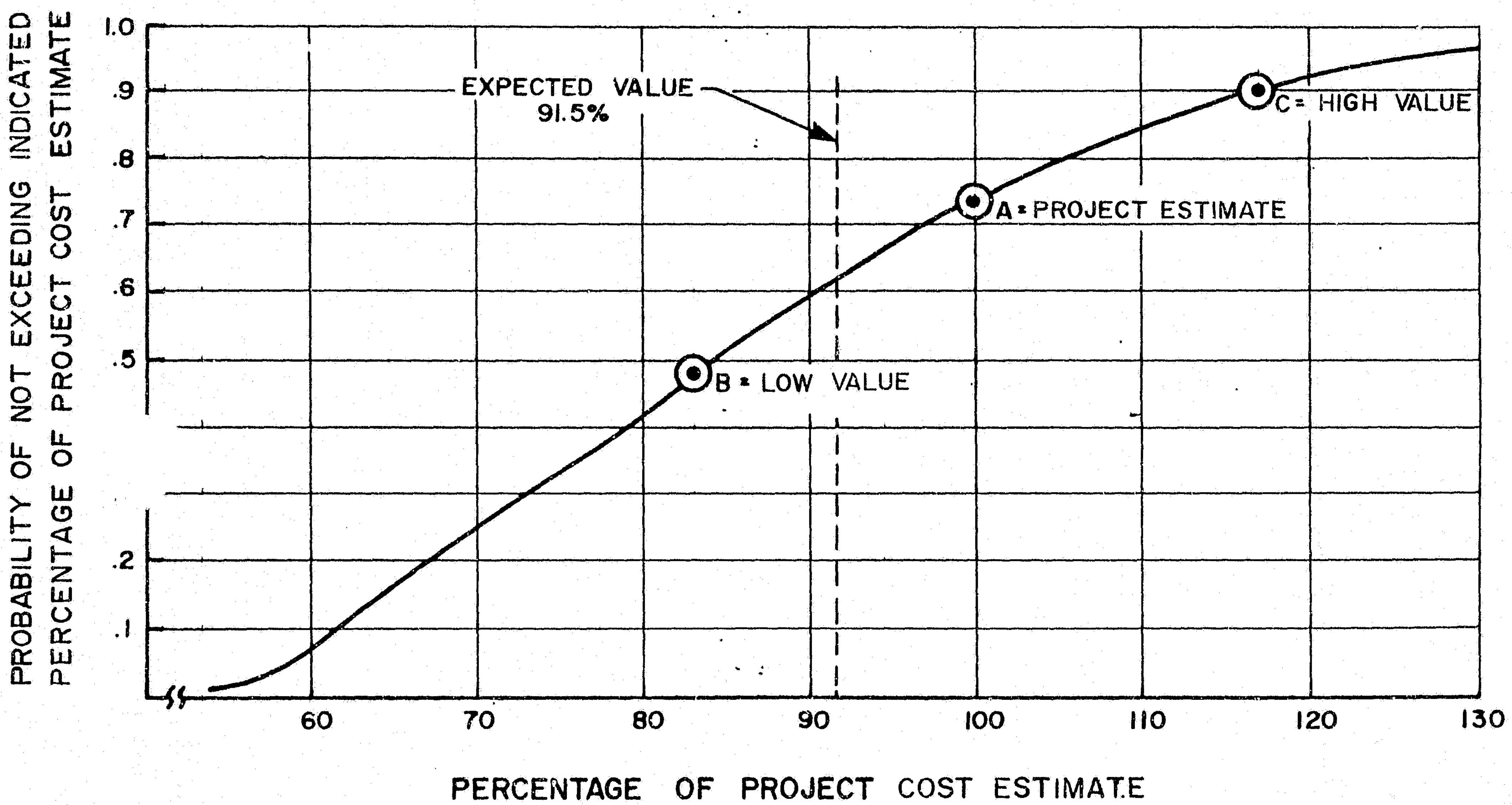
ACRES



CONTRIBUTION OF UNUSUAL RISKS AT THE ACTIVITY LEVEL FOR MAIN DAM FILL, LOWER PORTION

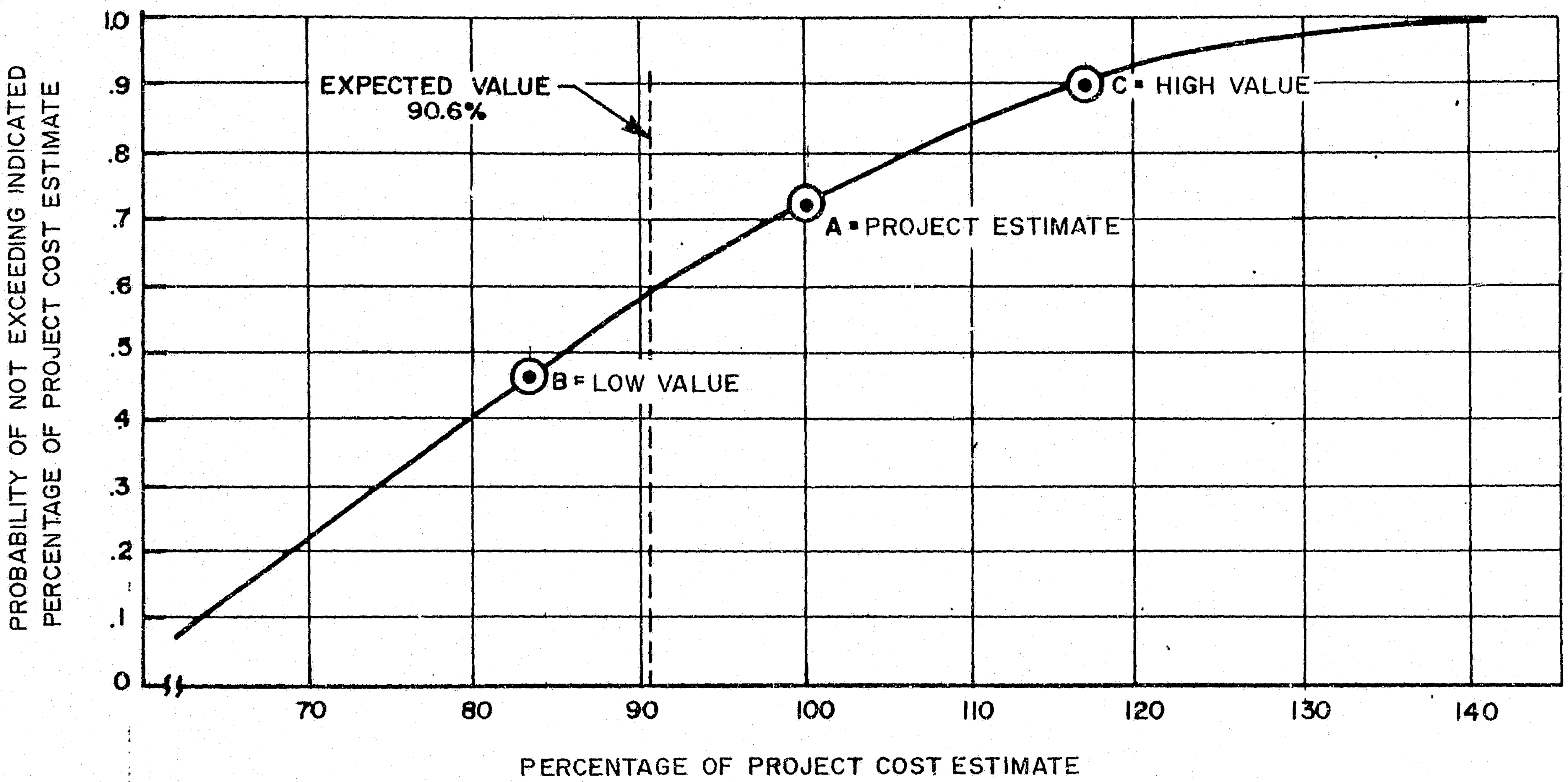
FIGURE 6.4

ACRES



CUMULATIVE PROBABILITY DISTRIBUTION OF DEVIL CANYON COSTS

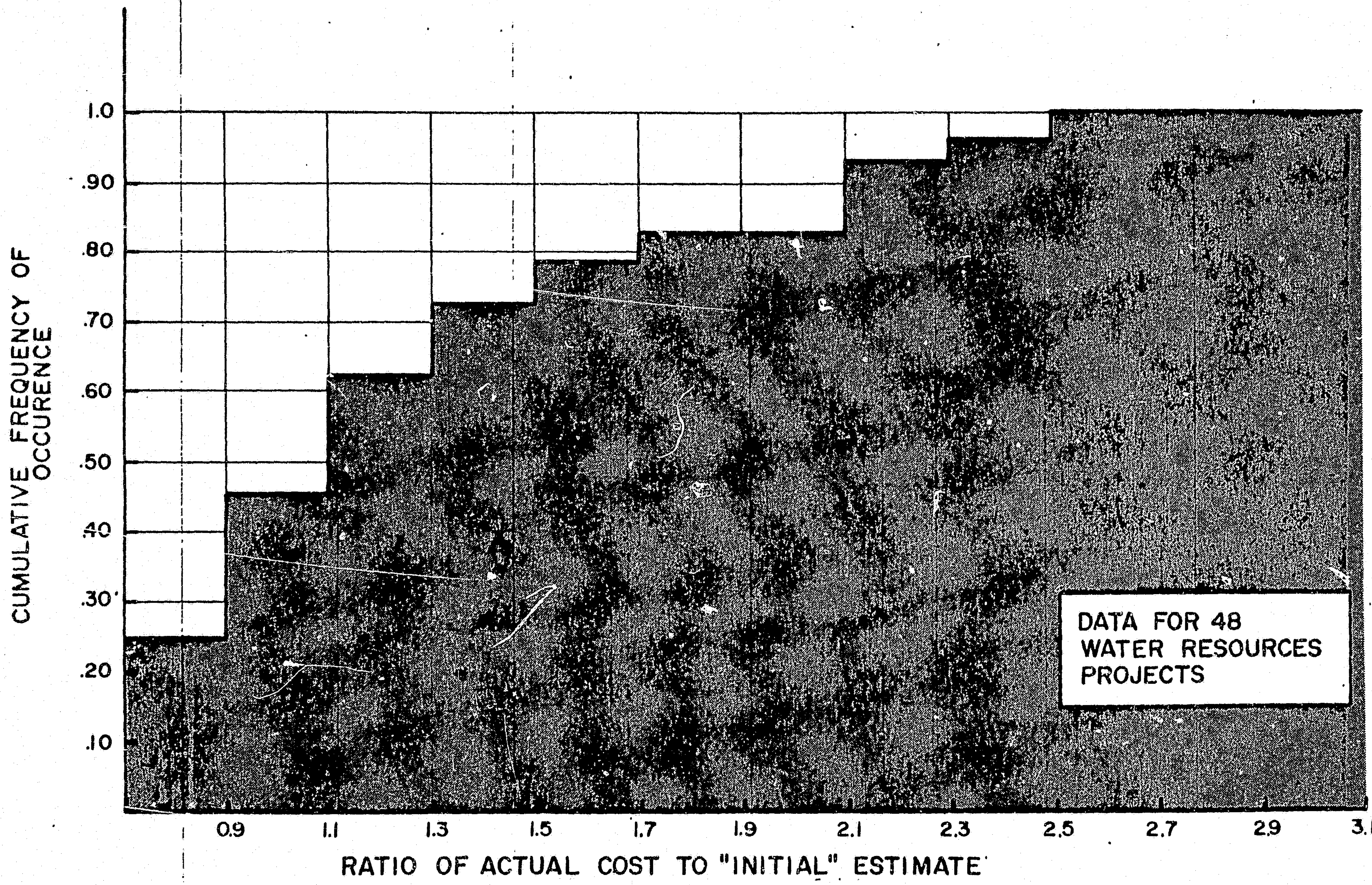
FIGURE 6.5



CUMULATIVE PROBABILITY DISTRIBUTION FOR SUSITNA HYDROELECTRIC PROJECT

ACRES

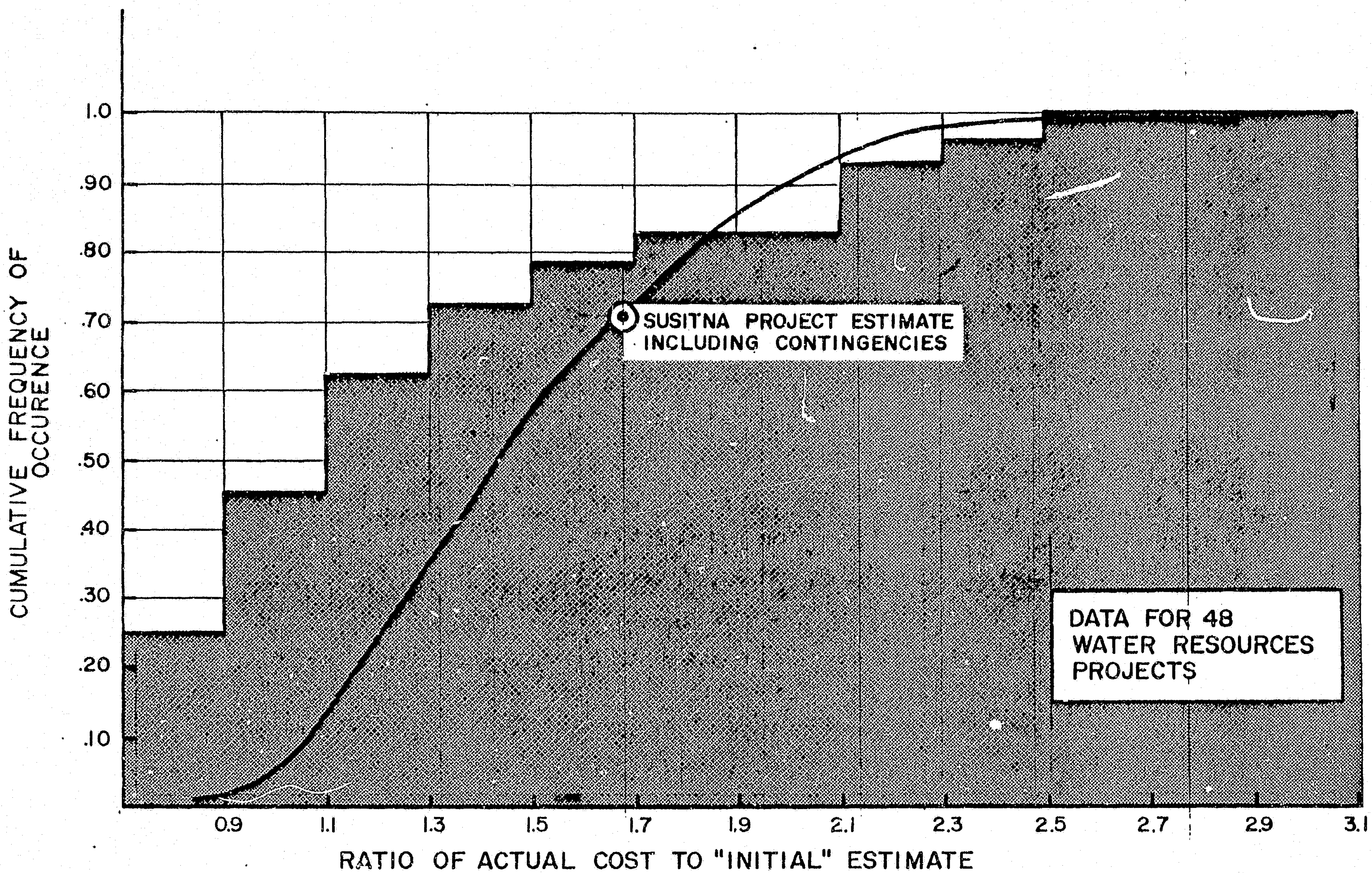
FIGURE 6.6



HISTORICAL WATER RESOURCES PROJECT COST PERFORMANCE (48 PROJECTS)

FIGURE 6.7

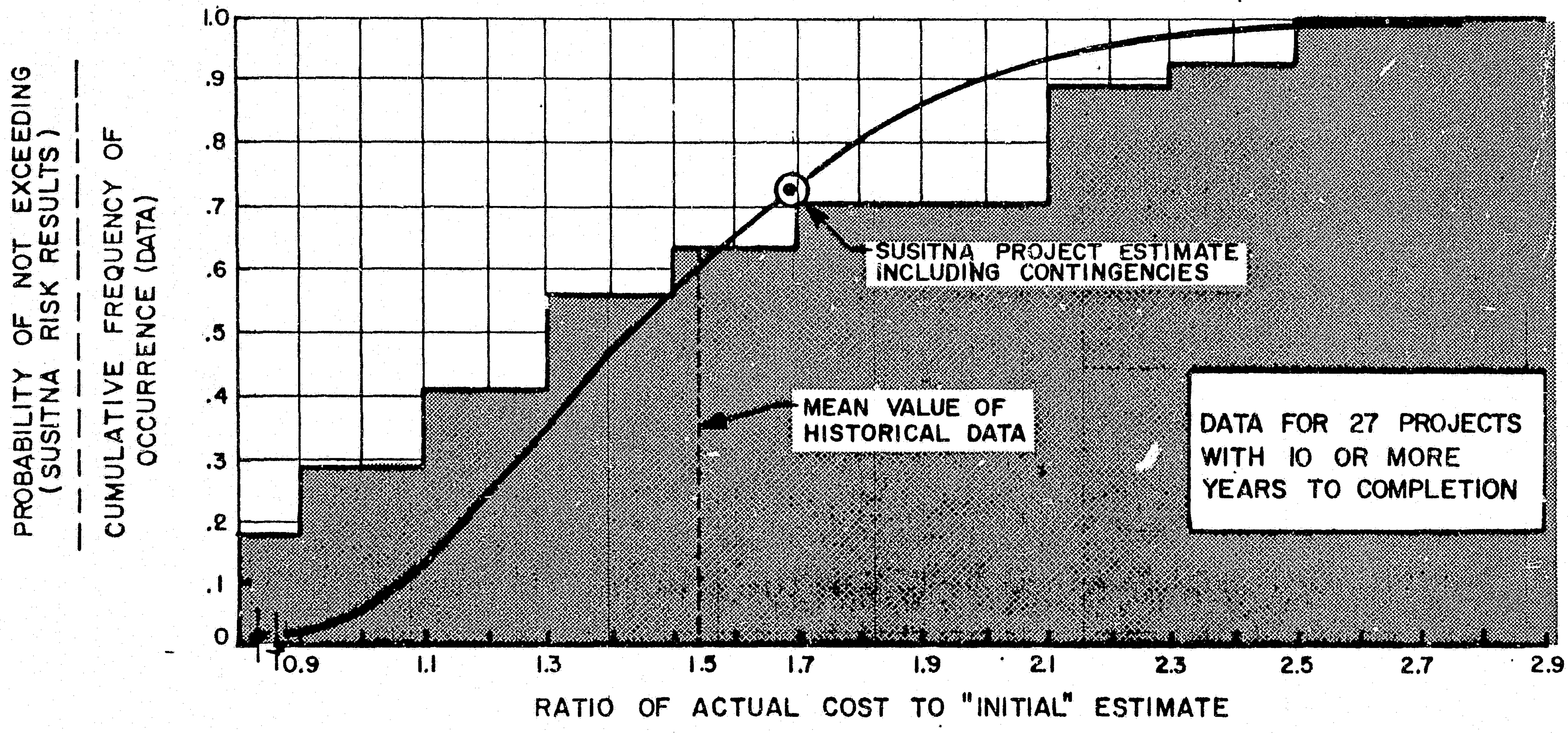
ACRES



COMPARISON OF SUSITNA RISK RESULTS WITH HISTORICAL WATER RESOURCES PROJECT COST PERFORMANCE (48 PROJECTS)

FIGURE 6.8

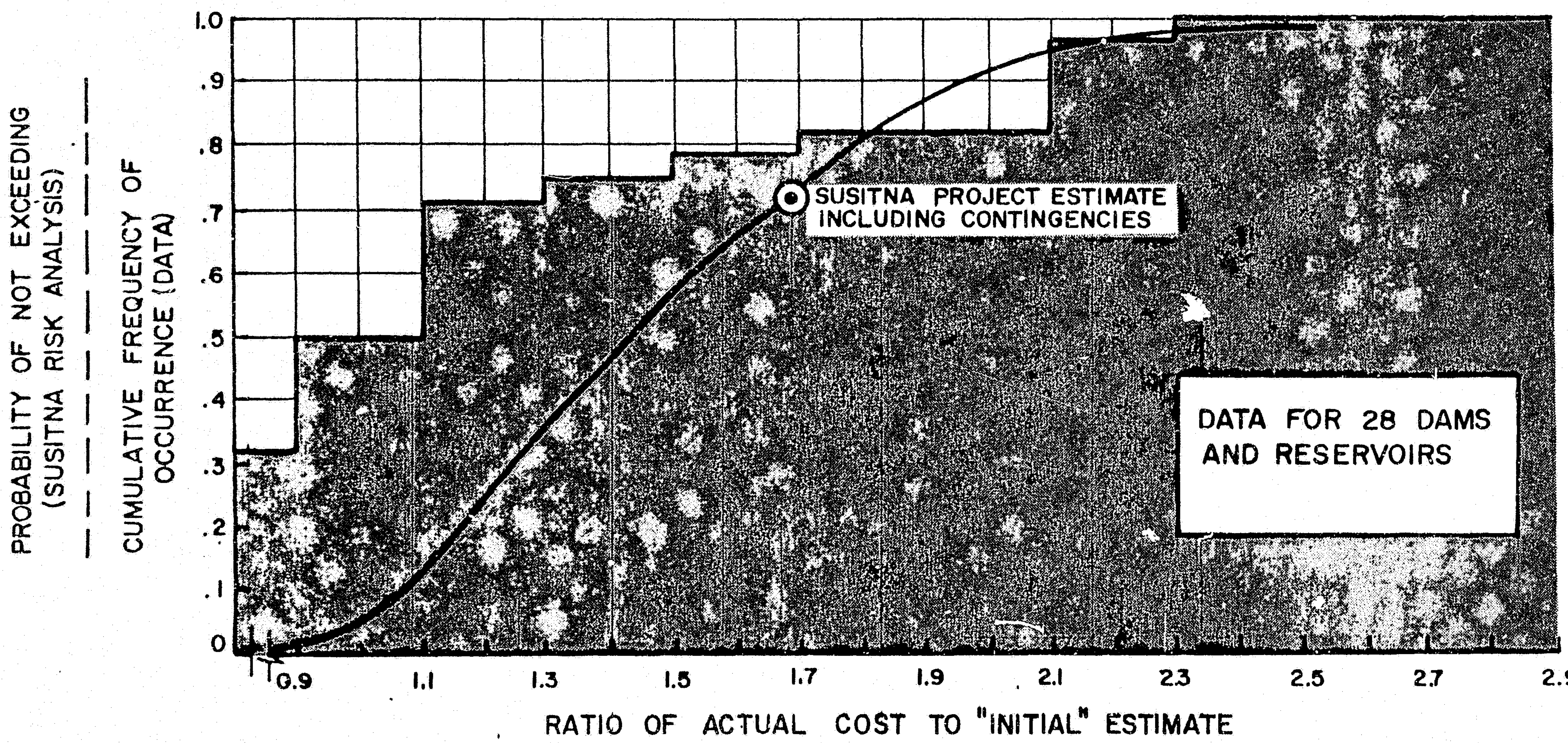
ACRES



COMPARISON OF SUSITNA RISK ANALYSIS RESULTS WITH HISTORICAL DATA FOR PROJECTS WITH 10 OR MORE YEARS BETWEEN "INITIAL" ESTIMATE AND COMPLETION

FIGURE 6.9

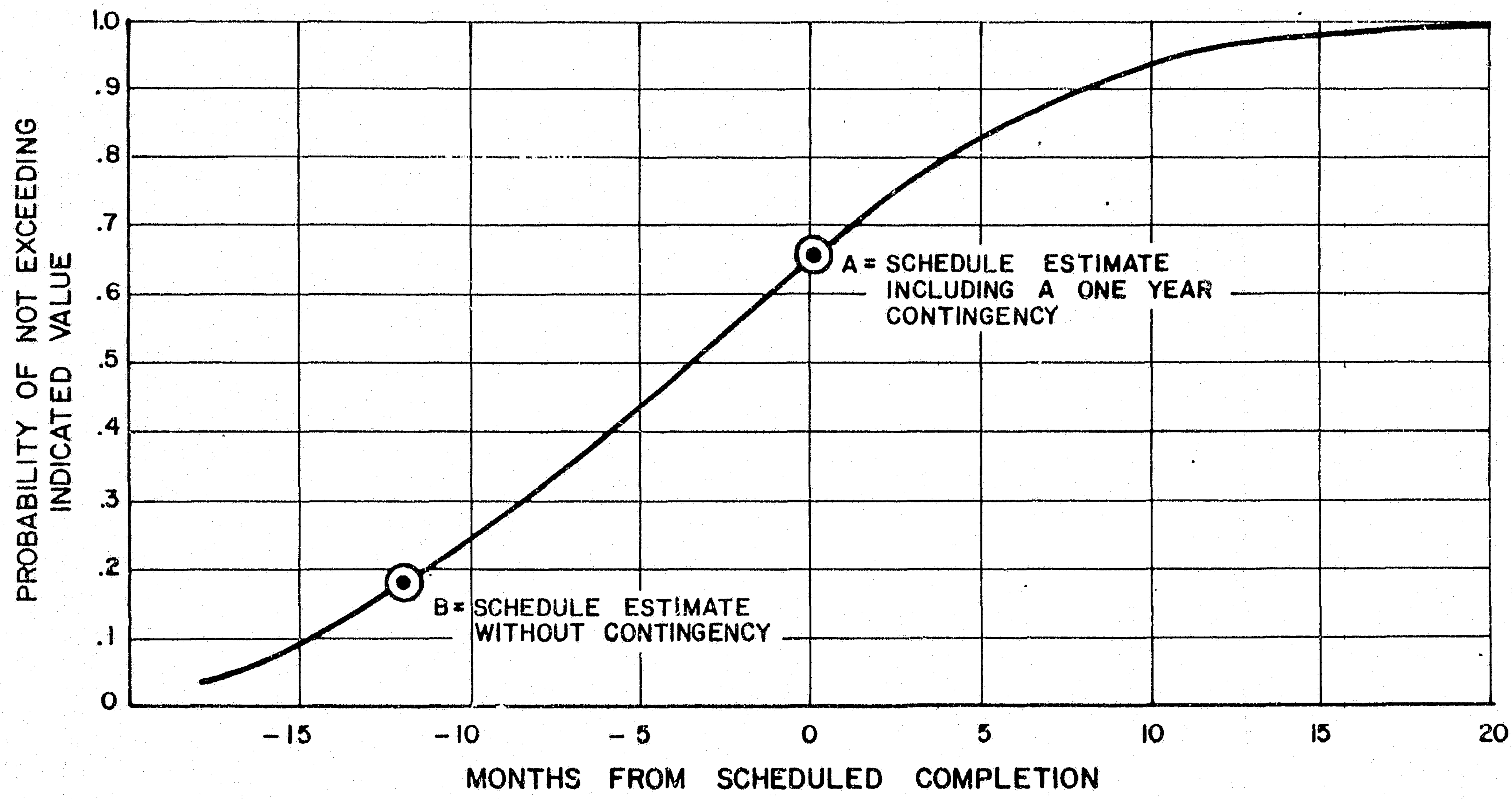
ACRES



COMPARISON OF SUSITNA RISK ANALYSIS RESULTS WITH HISTORICAL DATA FOR DAMS AND RESERVOIRS

FIGURE C.10

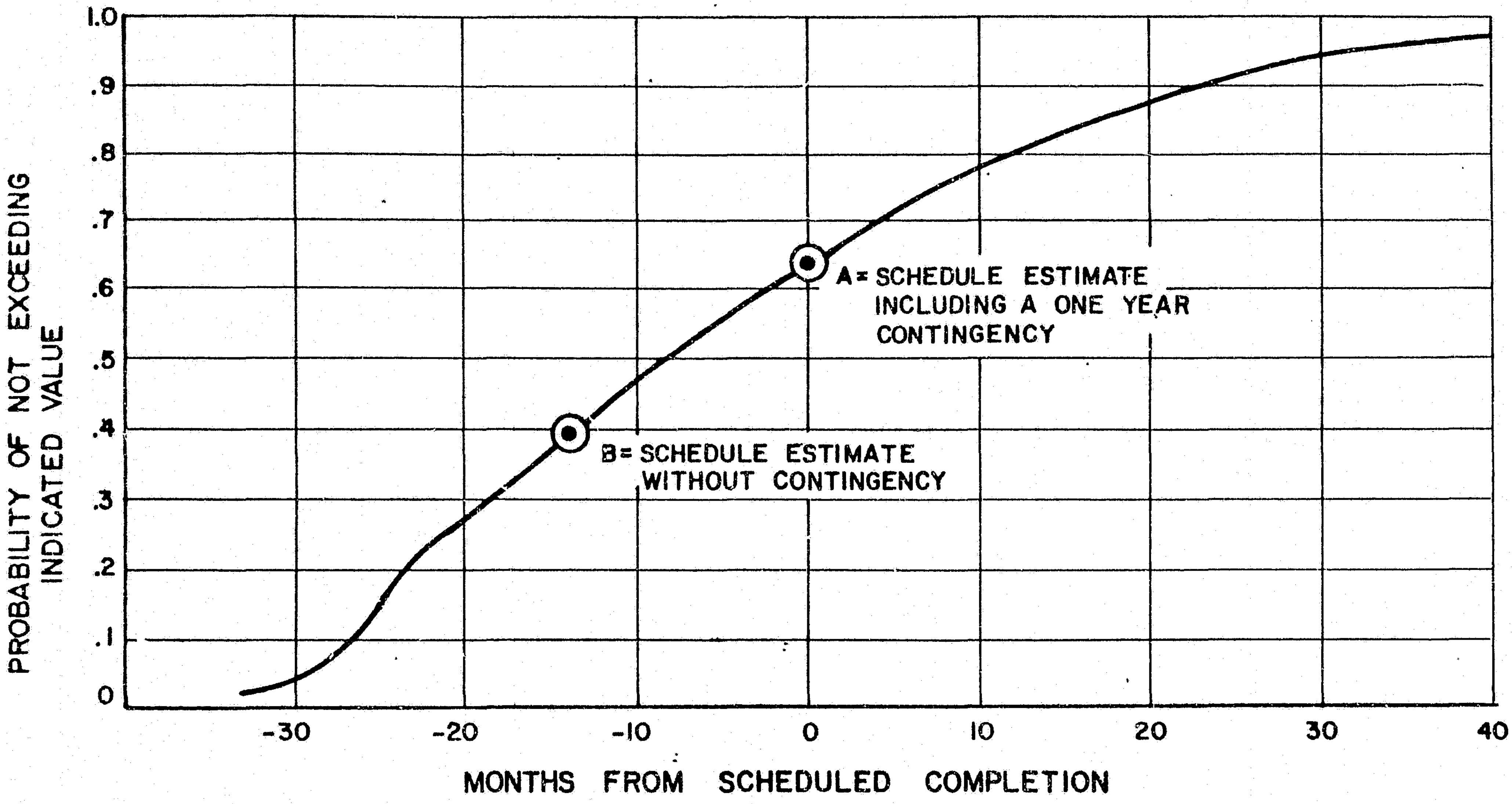
ACRES



WATANA SCHEDULE DISTRIBUTION EXCLUSIVE OF REGULATORY RISKS

FIGURE 6.11

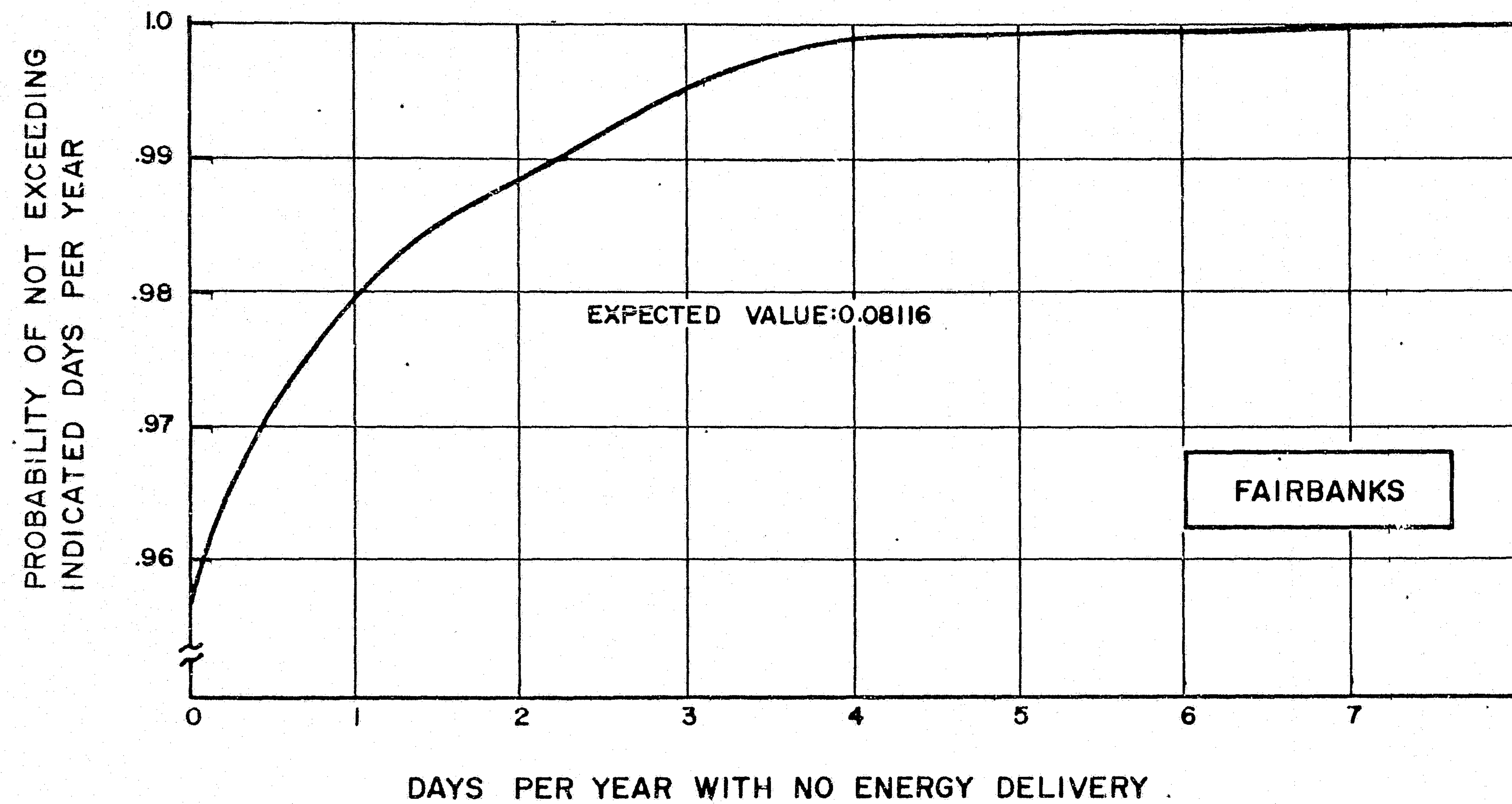
ACRES



WATANA SCHEDULE DISTRIBUTION INCLUDING THE EFFECT OF REGULATORY RISKS

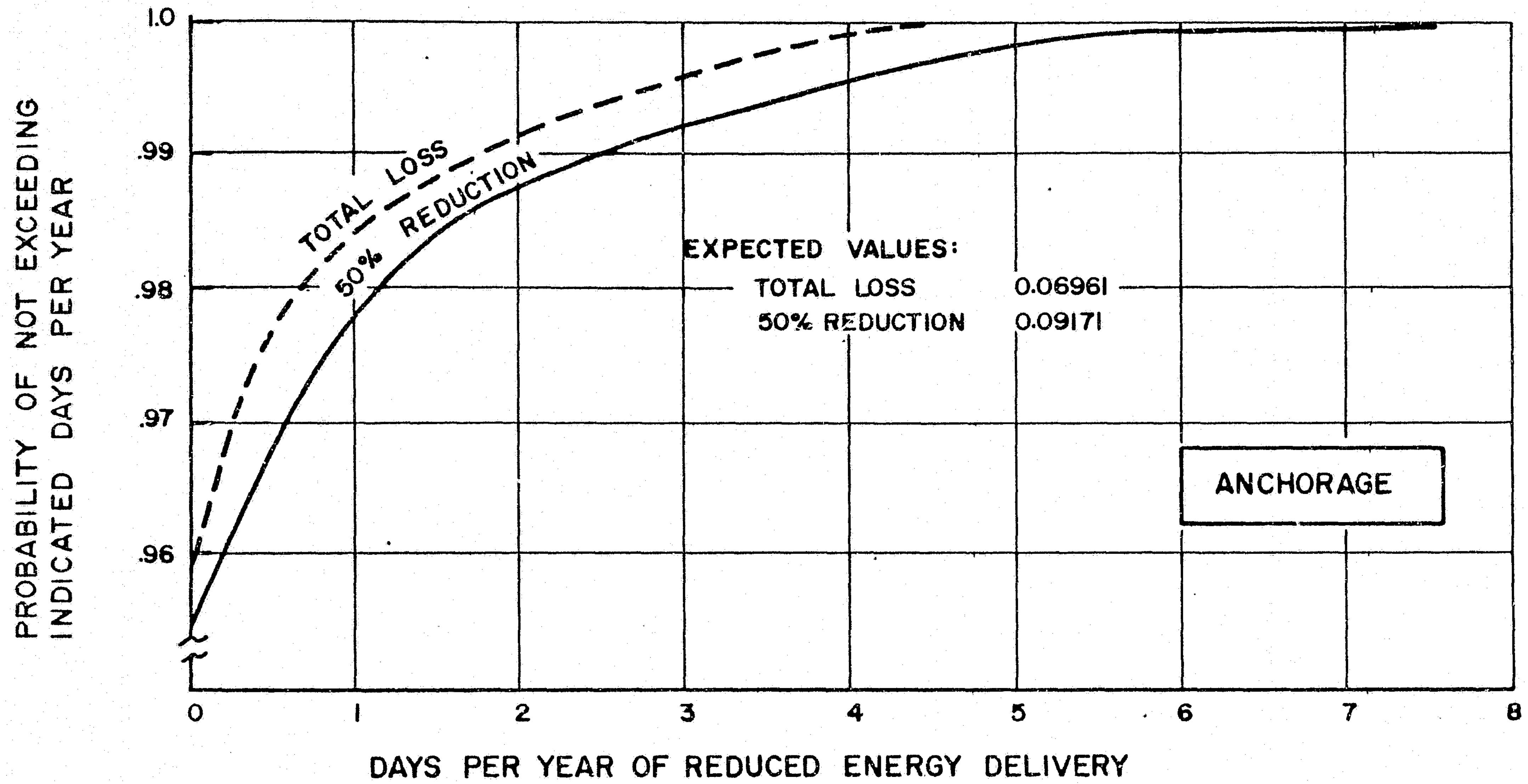
FIGURE 6.12

ACRES



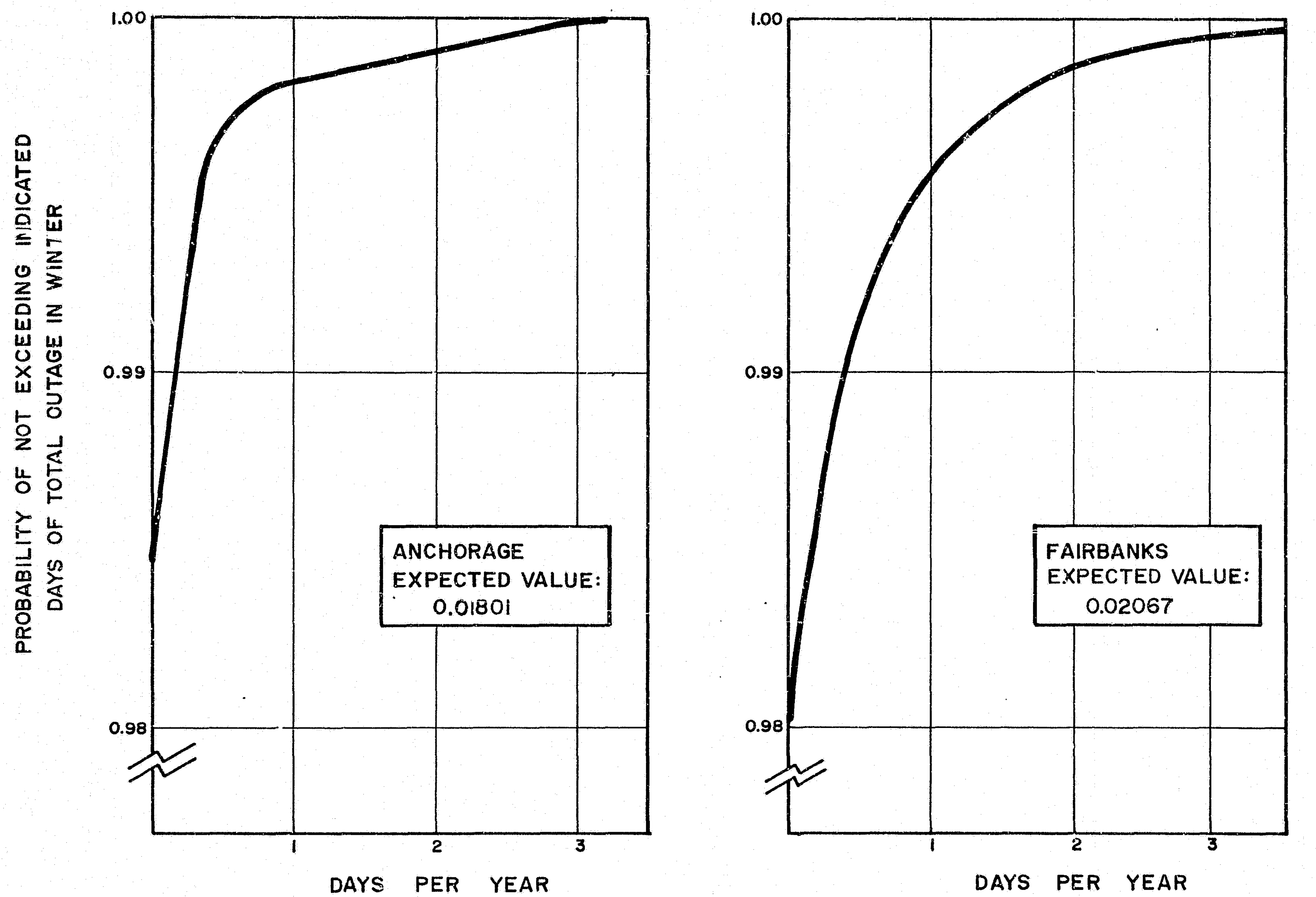
CUMULATIVE PROBABILITY DISTRIBUTION FOR DAYS PER YEAR WITH NO SUSITNA ENERGY DELIVERY TO FAIRBANKS

FIGURE 6.14



CUMULATIVE PROBABILITY DISTRIBUTION FOR DAYS OF REDUCED ENERGY DELIVERY TO ANCHORAGE

FIGURE 6.13



CUMULATIVE PROBABILITY DISTRIBUTION FOR TRANSMISSION SYSTEM EXCLUSIVE OF FLOOD AND LIGHTNING RISKS

FIGURE 6.15

ACRES

APPENDIX A

APPENDIX A - TRANSMISSION LINE RISK RESPONSE

A.1 - Purpose

The purpose of this analysis is to assess the consequences to the Railbelt electric utilities system due to the loss of Susitna generation. In the event a risk is realized as described in Section 4, responses have been formulated to provide emergency generation to the Anchorage and Fairbanks region.

A.2 - The Railbelt System in the Period 2000 to 2010

The system load resource balance under the medium load forecast for the period 2000 to 2010 is presented numerically in Table A.1 and graphically in Figure A.1. The rated capacity of Susitna Project will represent 44 percent of total system's capability of 1531 MW in year 2000 with the addition of Watana, increase to 62 percent in the year 2002 with the addition of Devil Canyon, and then remain at about that level through the year 2010. In case of a two-line transmission loss, capacity from Susitna will be reduced by approximately 37 percent. The system peak demand could still be met.

In the case of a complete loss of power generation from Susitna, the lack of capacity would be 22 percent of peak load in year 2000, and increase to 48 percent between 2005 and 2010. These capacity deficiencies in the Anchorage and Fairbanks region are discussed in the following section.

A.3 - Capacity Deficiencies in Anchorage and Fairbanks

In the event of a 100 percent loss of Susitna energy, the capacity deficiencies based on annual peak in Anchorage and Fairbanks are shown in Table A.2 and graphically in Figure A.2. In the Anchorage area, the capacity deficiency will be 11 percent of annual hourly peak in year 2000, and increase to about 40 percent between 2005 and 2010. In the Fairbanks area, the capacity deficiency would be 72 percent of annual hourly peak in year 2000, and increase to 81 percent in year 2005 and 92 percent in year 2010 (see Table A.3).

The annual peak is the maximum demand which occurs once in the year and therefore represents the single most critical period. Figures 1 and 2 use the annual peak for presenting the data. A more representative yearly analysis is based on typical weekday and weekend loads. Figures 3 and 4 use the normal peak loads from weekday and weekend analyses.

The capacity deficiencies in the two areas were analyzed more specifically for weekdays and weekends in years 2000, 2005 and 2010. The hourly loads for weekdays and weekend for the month of December in Anchorage area for years 2000, 2005 and 2010 are presented graphically in Figure A.3. The percentage of normal peak load during weekday and weekend for these years which would be unmet in the event of Susitna loss is as follows:

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Capacity Deficit - Anchorage

	2000	2005	2010
Weekday Peak	5%	38%	35%
Weekend Peak	0%	35%	31%

The hourly loads for weekday and weekend for the month of December in Fairbanks area for years 2000, 2005 and 2010 are presented graphically in Figure A.4. The percentage of normal peak load during weekday and weekend for these years which would be unmet in the event of Susitna loss is as follows:

Capacity Deficit - Fairbanks

	2000	2005	2010
Weekday Peak	66%	77%	90%
Weekend Peak	62%	74%	89%

A.4 - Measures to Meet Capacity Deficits

Alternative measures available include the following:

(a) Military Support

Current capacity of military installations is 58.8 MW in the Anchorage area including Elmendorf Air Force Base and Fort Richardson, and 46.5 MW in the Fairbanks area including Eielson Air Force Base, Fort Greeley and Fort Wainwright. Assuming that about 25 percent of military capacity can be tapped in an emergency, the capacity available would be 15 MW or 2 percent of peak load in Anchorage, and 12 MW or 6 percent of peak load in Fairbanks.

(b) Temporary Major Conservation by Residential Customers

In the Anchorage area, residential consumption constitutes nearly 50 percent of total electric energy. Temporary major conservation efforts by residential customers is a potential measure to meet deficiencies of capacity.

In the Fairbanks area, residential consumption represents about 30 percent of total electric energy. Temporary major conservation by residential customers in Fairbanks will not be sufficient alone to meet an outage of Susitna delivery. Other measures will be necessary.

(c) Load Shedding in Commercial, Industrial and Governmental Use

Available data groups commercial, industrial and governmental into one class of customers. Electric energy consumption in this group constitutes about 50 percent of total in Anchorage area and 70 percent in the Fairbanks area. Load shedding in this class of customers would contribute substantially in reducing demand, particularly in the Fairbanks area.

(d) Rotating Blackouts to Reduce Peak

Rotating blackouts to reduce peak could be used in the Anchorage area where the deficiencies of capacity were estimated to be less than 40 percent. Deficiencies of capacity in the Fairbanks area would be larger, and rotating blackouts can be used together with major residential conservation and load shedding in commercial and industrial users.

(e) Maintaining Old Plants for Standby Reserve with 24 - 36 Hour Emergency Startup

During the period 1990 to 2010 there are expected to be a total of 316.3 MW of capacity retirements in the Anchorage area of which 234 MW will be from the Chugach Electric Association and 82 MW from Anchorage Municipal Light and Power. In the Fairbanks area, the retirements will have a total capacity of 282 MW of which 222 MW will be from the Golden Valley Electric Association and 60 MW from the Fairbanks Municipal Utilities System. These estimates are based on project lives assumed for generation planning purposes. These plants could be maintained for standby reserve with 24 - 36 hour emergency startup.

A.5 - Formulation of Transmission Loss Responses

The responses were formulated with emphasis on military support, load shedding and emergency conservation. Because the capacity deficits could be met by these alternative emergency responses, maintaining retired plants was not considered as a most likely choice for emergency planning. However, some plants may be designated for standby reserve and maintained to meet some portion of the capacity deficit under emergency conditions. This would reduce the level of conservation and load shedding required to respond to an emergency outage.

The methodology for formulating responses was to add military emergency capacity, then compute percentages of load shedding and conservation that would meet the deficiencies.

In the Anchorage area, the capacity deficiencies in case of loss of Susitna generation could be met by the following measures (see Figure A.5).

- Military capacity could provide emergency generation. Assuming about 25 percent of military capacity can be tapped in an emergency, this would provide 15 MW of capacity or about 2 percent of peak load in the Anchorage area.
- Load shedding of commercial, industrial and governmental uses to a weekend usage level. A comparison of hourly loads for weekday and weekend indicates that this measure will reduce load by about 20 percent.
- Major emergency conservation in residential uses should be able to reduce load by at least 16 percent.

All these three measures will allow the electric system in the Anchorage area to meet deficiencies of capacity caused by the 100 percent loss of Susitna delivery. Partial loss of Susitna power due to the loss of two of three transmission lines would not cause capacity deficiencies in Anchorage despite the assumption that Fairbanks load is always served.

In the Fairbanks area, the capacity deficiencies in case of loss of Susitna delivery would be larger. The same measures which were identified for Anchorage could reduce these deficiencies in Fairbanks (see Figure A.6).

- Military capacity: 25 percent of military capacity can be tapped, thus response it could provide 12 MW of capacity or 6 percent of Fairbanks peak load.

- Load shedding of commercial, industrial and governmental uses to a weekend level will reduce load by about 20 percent. As discussed earlier, this class of consumers has 70 percent share of the area consumption. A blackout of these loads could reduce hourly load by up to 70 percent.

- Major conservation in residential uses. The residential consumption represents about 30 percent of the area total. A reduction of 50 percent of residential uses by major conservation will reduce hourly load by 15 percent.

A combination of all three measures will meet about 90 percent of peak load in the Fairbanks area. It will therefore meet the deficiencies of capacity in the area estimated from total loss of Susitna power.

A.6 - Summary

In summary, the responses in case of loss of 100 percent Susitna delivery are as follows:

In the Anchorage area:

- Use military support: 25 percent of military capacity

- Load shedding of commercial, industrial and governmental uses to a weekend level

- Major conservation of residential uses.

In the Fairbanks area:

- Use military support: 25 percent of military capacity

- Blackout all commercial, industrial and governmental loads

- Blackout 50 percent of residential load by rotating or strict conservation measures.

Partial loss of Susitna power (two of three lines from the Susitna Basin) does not impact Anchorage or Fairbanks since 810 MW of capacity can be transmitted on one line. This assumes of course that adequate switching capability exists along the intertie.

TABLE A.1: RAILBELT SYSTEM LOAD RESOURCE BALANCE

Year	System Peak Demand MW	Capabilities,[1] MW: Susitna Project	Other Plants[2]	Total System	Reserve MW	Partial[3] Loss of Susitna Capability: Capability	Reserve (Deficit) MW	100% Loss of Susitna Capability: Capability	Reserve (Deficit) MW
2000	1,084	680	851	1,531	447	1531	447	851	(233)
2001	1,121	680	851	1,531	410	1531	410	851	(270)
2002	1,158	1,280	798	2,078	920	1608	450	798	(360)
2003	1,196	1,280	745	2,025	829	1555	359	745	(451)
2004	1,233	1,280	745	2,025	792	1555	322	745	(488)
2005	1,270	1,280	657	1,937	667	1467	197	657	(613)
2006	1,323	1,280	634	1,914	591	1444	121	634	(689)
2007	1,377	1,280	704	1,984	607	1514	137	704	(673)
2008	1,430	1,280	748	2,028	598	1558	128	748	(682)
2009	1,484	1,280	747	2,027	543	1557	73	747	(737)
2010	1,537	1,280	817	2,027	560	1557	20	817	(720)

1/ Capacity at annual system peak under medium load forecast.

2/ Includes about 155 MW of capability from other hydro plants.

3/ The load carrying capability of one 345 kV transmission line is approximately 63 percent of Susitna project load, therefore the loss of Susitna is 37 percent.

TABLE A.2: LOAD RESOURCE ANALYSIS - ANCHORAGE AREA

Year	Area Annual Peak Demand	Capability (MW) Other Plants	Susitna Power to Anchorage: Partial Loss 1/	Susitna Power to Anchorage: Full Loss	Area Load Reserve/(Deficit) Without Susitna (MW): Partial Loss of Power MW Reserve	Partial Loss of Power % Reserve	100% Loss of Power MW (Deficit)	100% Loss of Power % Deficit
2000	860	766	457	0	363	42	(94)	11%
2001	894	766	453	0	325	36	(128)	14%
2002	930	715	582	0	367	39	(215)	23%
2003	967	662	581	0	276	29	(305)	32%
2004	1,006	662	588	0	239	24	(344)	34%
2005	1,047	604	580	0	145	24	(443)	42%
2006	1,093	604	585	0	91	8	(489)	45%
2007	1,141	674	575	0	108	9	(467)	41%
2008	1,192	717	572	0	97	8	(475)	40%
2009	1,244	716	570	0	42	3	(528)	42%
2010	1,299	786	572	0	59	5	(513)	40%

1/ Partial loss reflects 63 percent of Susitna power transmitted minus Fairbanks load.

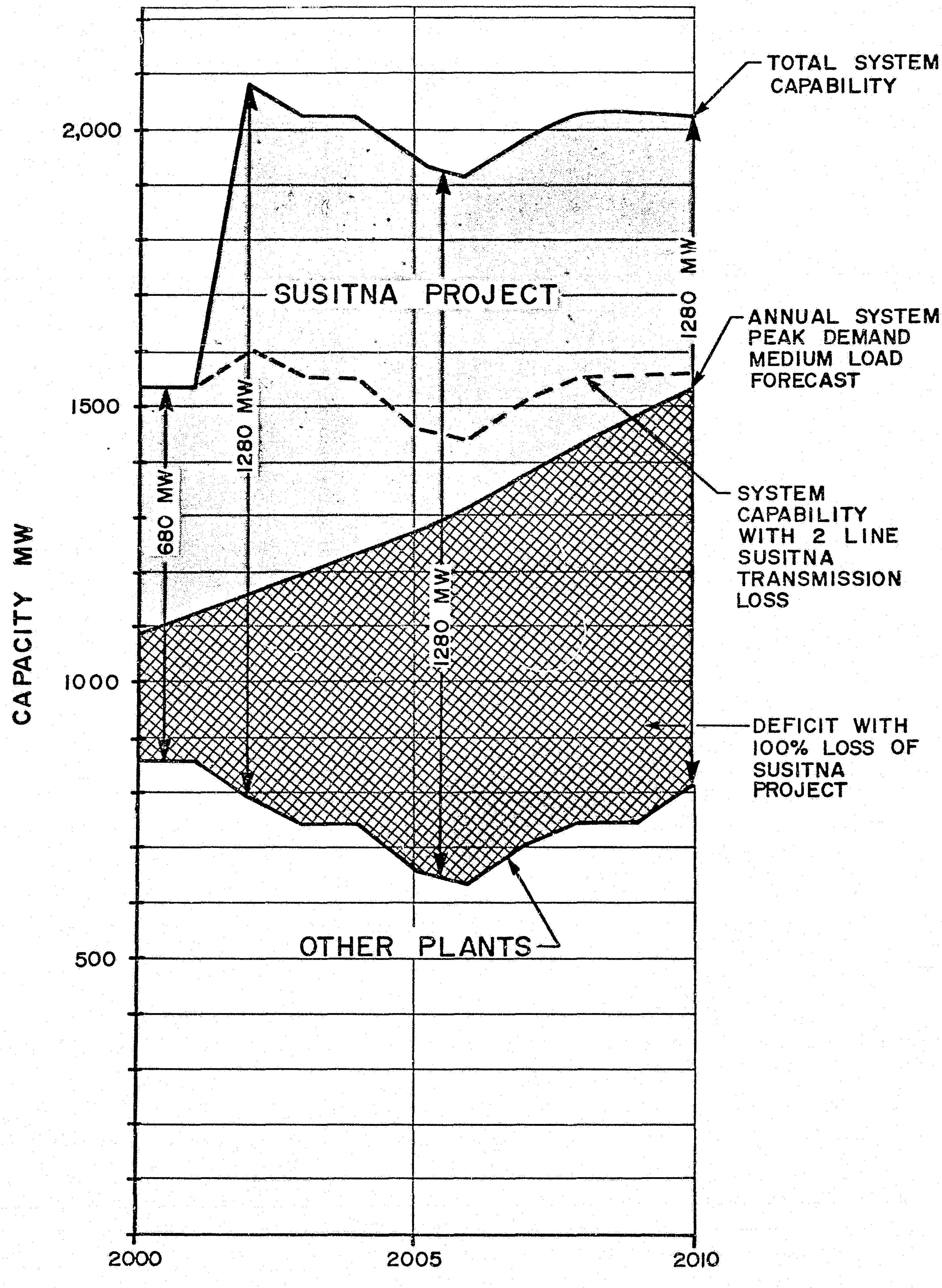
Year	Anchorage Weekday Peak Load	Capability With Loss of Susitna: Partial	Capability With Loss of Susitna: 100%	Area Load Reserve/(Deficit) Without Susitna (MW): Partial Loss of Power MW Reserve	Partial Loss of Power % Reserve	100% Loss of Power MW (Deficit)	100% Loss of Power % Deficit
2000	803	1223	766	420	52	37	0
2005	975	1184	604	209	21	(371)	38
2010	1203	1358	786	155	13	(631)	53

TABLE A.3: LOAD RESOURCE ANALYSIS - FAIRBANKS AREA

Year	Fairbanks Peak Load (MW)	Other Plant Capability (MW)	Area Load Reserve/(Deficit) 1/ (MW)	Deficit (%)
2000	223	63	(160)	72
2001	227	63	(164)	72
2002	228	63	(165)	73
2003	229	63	(166)	73
2004	227	63	(164)	72
2005	222	42	(180)	81
2006	230	19	(211)	92
2007	235	19	(216)	92
2008	238	19	(219)	92
2009	240	19	(221)	92
2010	238	19	(219)	92

1/ In case of 100 percent loss of power from Susitna.

Year	Fairbanks Weekday Peak Load (MW)	Capability With 100% Loss of Susitna (MW)	Area Load Reserve/ (Deficit) (MW)	% Deficit (%)
2000	185	63	(122)	66
2005	183	42	(141)	77
2010	198	19	(179)	90



RAILBELT SYSTEM LOAD RESOURCE BALANCE

SEE TABLE 1

FIGURE A.1

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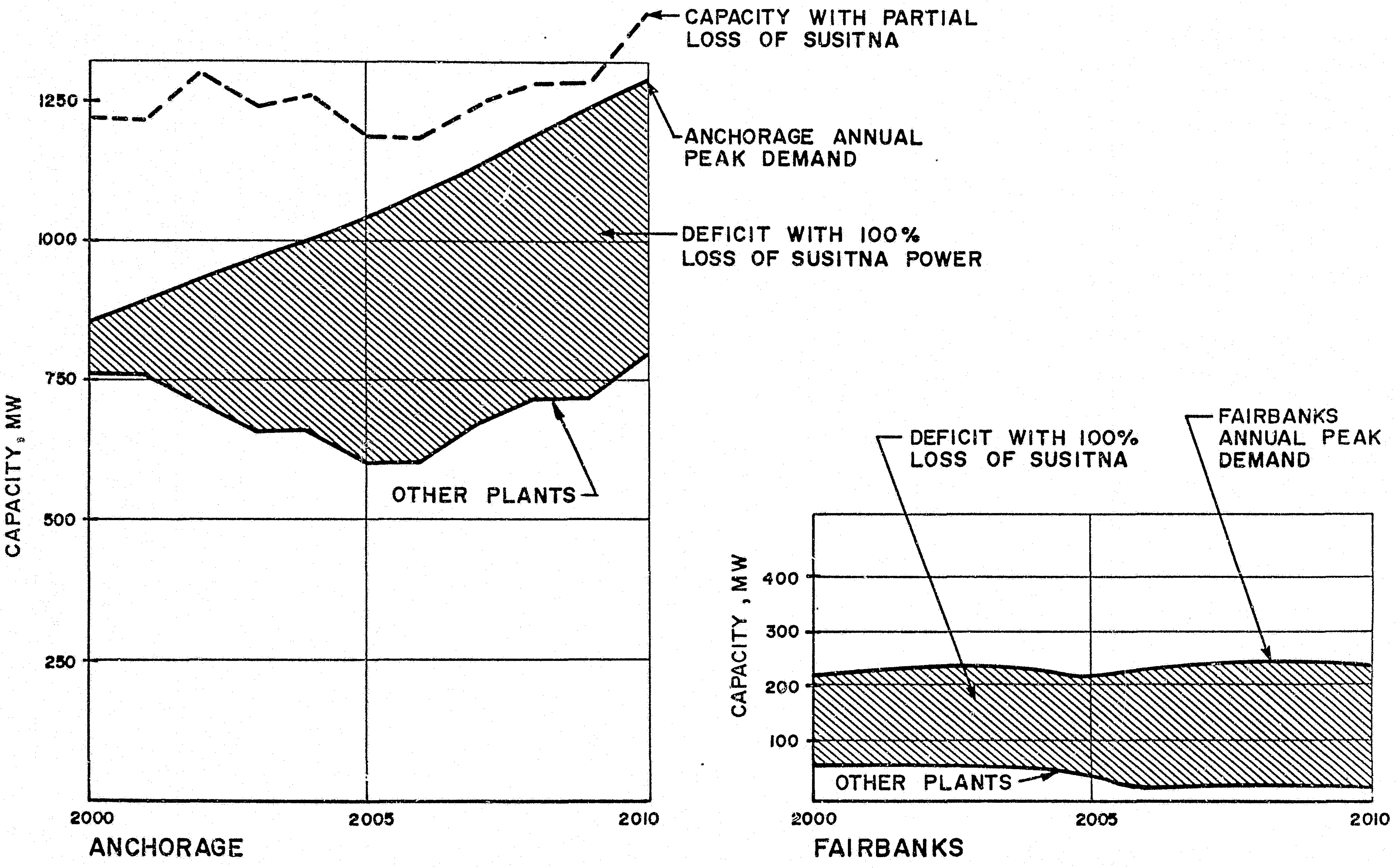

LOAD RESOURCE BALANCE IN ANCHORAGE AND FAIRBANKS AREAS

FIGURE A.2

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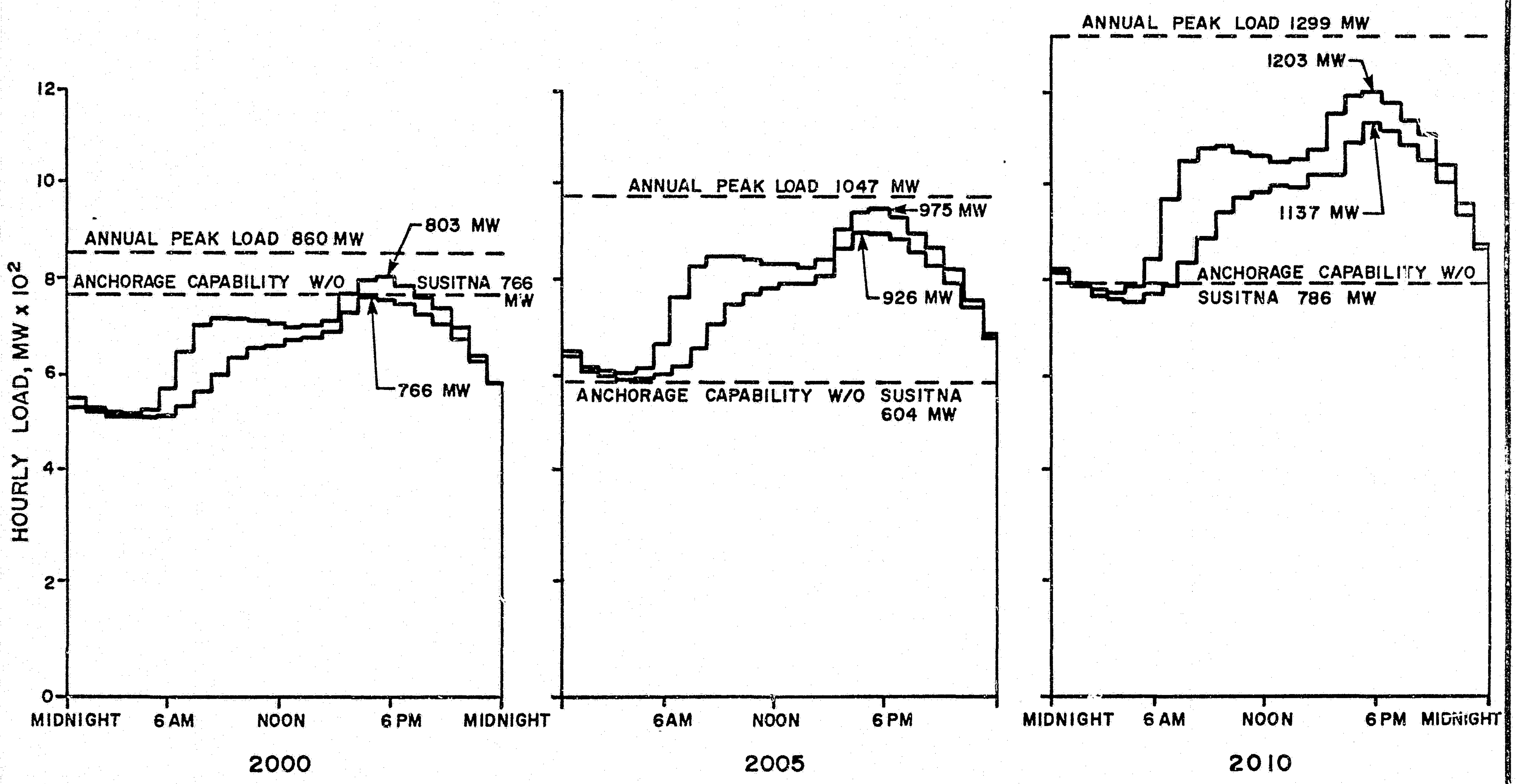

ANCHORAGE HOURLY LOADS

FIGURE A.3

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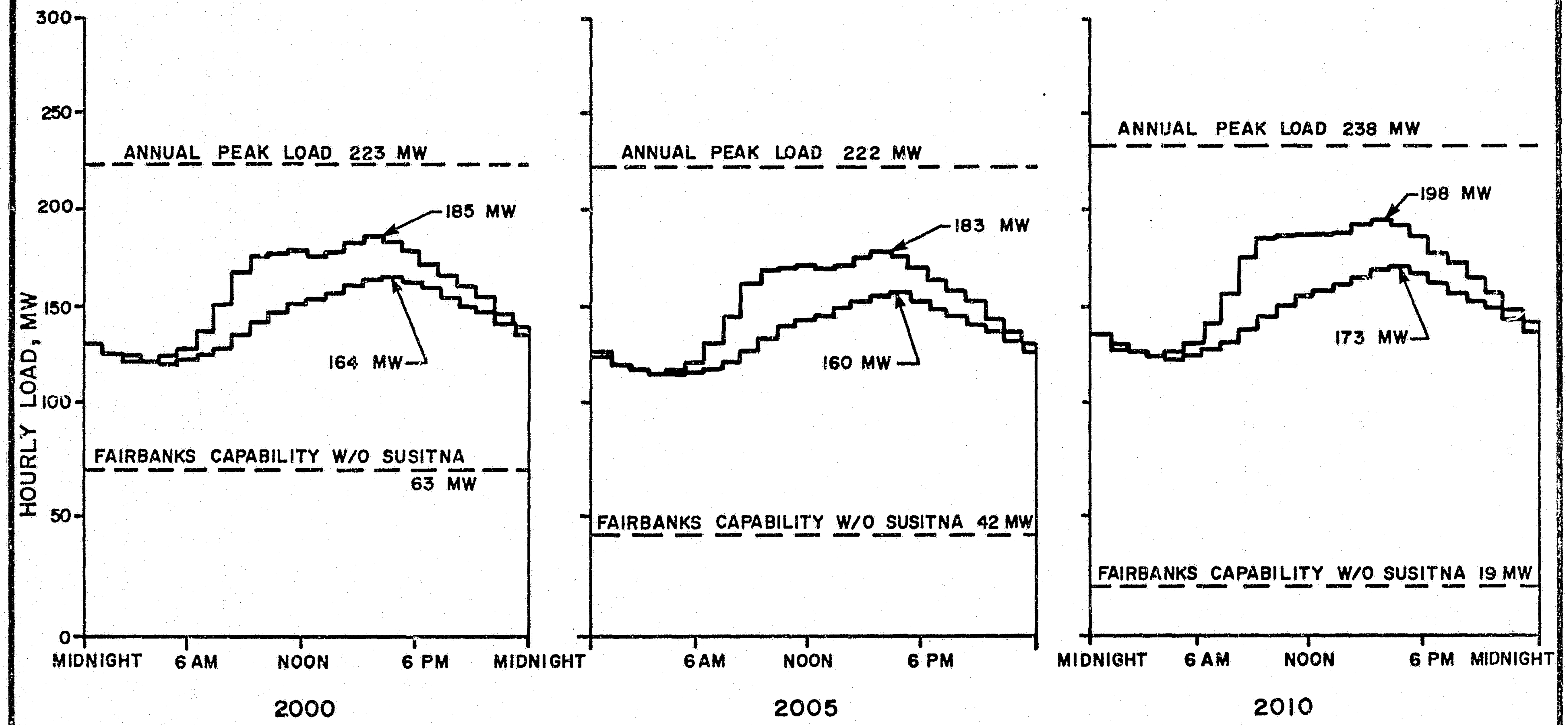
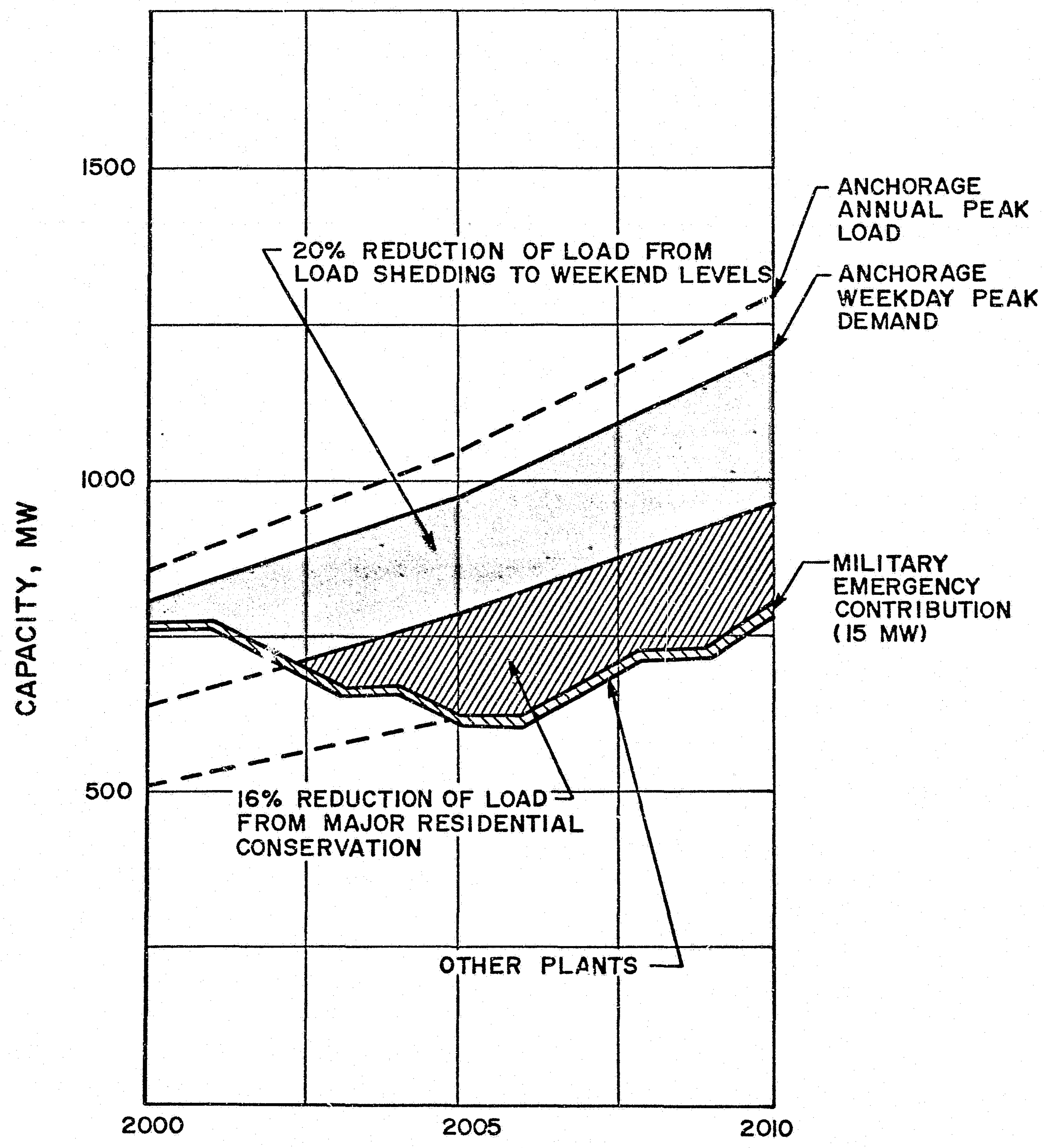


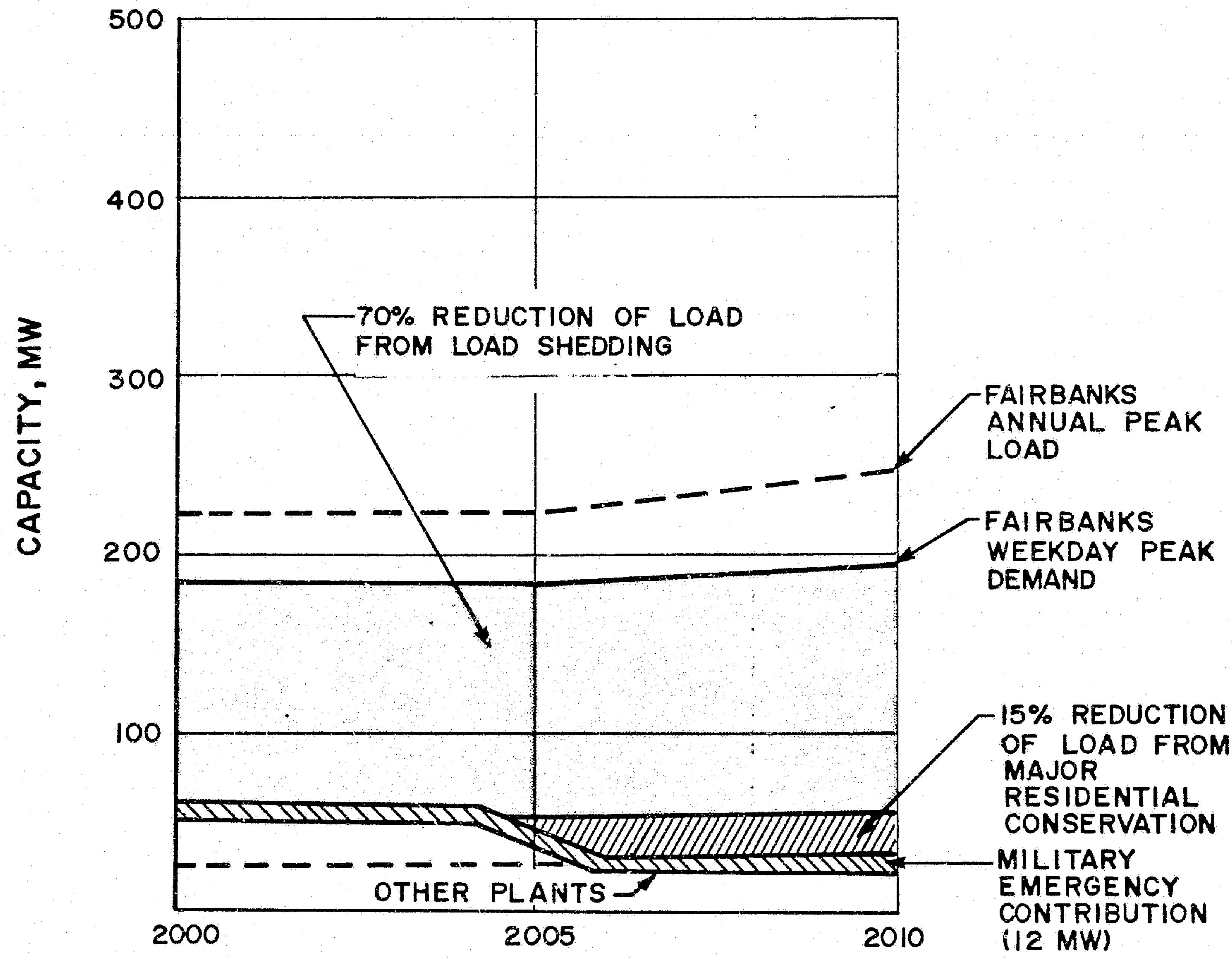
FAIRBANKS HOURLY LOADS

FIGURE A.4



ANCHORAGE TRANSMISSION LOSS RESPONSES

FIGURE A.5



FAIRBANKS TRANSMISSION LOSS RESPONSES

FIGURE A.6