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Simplified Framework Evaluation of Large Water Resource Project Impacts

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SIMPLIFIED FRAMEWORK EVALUATION OF LARGE WATER RESOURCE PROJECT IMPACTS

by

BRIAN WOODBRIDGE CLOWES

A dissertation submitted in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY
in
SYSTEMS SCIENCE

Portland State University

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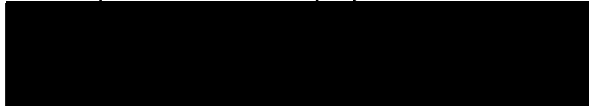
AN ABSTRACT OF THE DISSERTATION OF Brian Woodbridge Clowes for the

Doctor of Philosophy in Systems Science presented December 9, 1987.

TITLE: Simplified Framework Evaluation of Large Water Resource Project
Impacts.

APPROVED BY MEMBERS OF THE DISSERTATION COMMITTEE:

Roy Koch, Chairman

Vernon Bissell

Harold Linstone

Abdul Qayum

Brian Stipak

The document most frequently used to support a water resource
project's economic feasibility is the commercial benefit-cost analysis,
which quantifies tangible and direct project consequences. The
objective of this type of analysis is simply to maximize net monetary

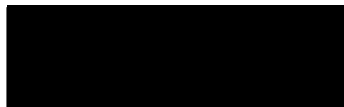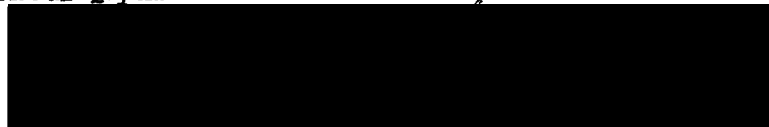benefits. This analysis assigns an arbitrary monetary value to ecological and social disruptions, if it does not ignore these effects entirely. An improvement on this method is the social benefit-cost analysis, which assesses some intangible costs such as air and noise pollution. Unfortunately, even the social analysis usually neglects the sometimes profound effects that a large water resource project has upon quality of life, particularly with regards to massive relocations.

The purpose of this dissertation is to resolve these problems by presenting a method by which a water resource study team may use five unique viewpoints - technical, organizational, personal, social, and environmental - to quantify and compare the true benefits and costs of project construction and operation.

The study team begins by rigorously documenting the three general categories of project consequence (economic, social and environmental) and assigning each benefit or cost a relative value within category according to perceived positive or negative effects. The second step is to use these quantifications to produce three impact vs. dam height curves. The final and most difficult step in this study process is to assign a relative weight to the respective economic, social, and environmental impact clusters, depending on national priorities and the biases and personal viewpoints of the decisionmaker(s). The final product of this procedure is a single curve which is used to further investigate and assess the overall feasibility of a water resource project and the 'optimum' range of dam heights.

All of the possible impacts of a large water resource project, whether they be tangible or intangible, should be investigated in order to produce an authentic indicator of project efficiency. The only way to insure that all impacts are properly accounted for is to perform an exhaustive examination of a water resource project from the five perspectives mentioned above.

The body of this dissertation is an example analysis based upon the proposed Three Gorge Dam and Reservoir on the Yangtze River in the People's Republic of China. This project will be the world's largest power plant at 13,000 megawatts. Because of its size, anticipated impacts, and the interest it has generated all over the world, the Three Gorge project is considered the ideal subject of a comprehensive multiple perspective analysis as described in this study.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

The first step is to measure whatever can be easily measured.
   This is OK as far as it goes.
The second step is to disregard that which can't be measured,
   or give it an arbitrary quantitative value. This is artificial
   and misleading.
The third step is to presume that what can't be measured easily
   really isn't very important. This is blindness.
The fourth step is to say that what can't be easily measured
   really doesn't exist. This is suicide.

> — D. Yankelovich, quoted by H. Linstone,
> Multiple Perspectives for Decision Making

STATEMENT OF THE PROBLEM

Deficiencies of the Standard Benefit-Cost Analysis.

The document most widely used to support the economic feasibility of a large water resource project is a technically-oriented, or 'commercial' benefit-cost analysis. This type of study typically stresses the evaluation of direct and tangible project consequences. Since negative intangible impacts may be quite difficult to define, they may be either totally ignored or 'mitigated' by the assigning of an arbitrary and generally inadequate percentage of project funds. For example, it is common practice in the United States for Federal water resource agencies to allocate one percent of project expenditures before interest during construction to the salvaging of cultural and historic resources. In many cases, this amount is pitifully inadequate.

A commercial benefit-cost analysis also commonly ignores the question of project sociologic impacts caused primarily by the alleviation of flood threats and by relocations performed to make way for project construction. It may be assumed that a group of relocated persons will be content because they have been moved to land and quarters with an equivalent or greater market value than those they have been forced to leave. This problem is particularly acute in developing countries, and can lead to disastrous impacts being imposed upon small groups of relatively powerless persons.

Objective of the Social Benefit-Cost Analysis.

A 'social' analysis improves on the purely technical orientation of the commercial study considerably by taking a second step; it accounts for many intangible project effects such as noise and air pollution. While a commercial analysis seeks simply to maximize profits or net benefits, a social analysis is more complete because it seeks to maximize social welfare over time.

The Requirements of a Complete Study.

Even though a properly outlined social benefit-cost analysis will account for most intangibles, most water resource study teams usually neglect to take the third and final necessary step towards the most complete possible study. In almost all cases, the major negative sociological and environmental effects brought on by project construction are either ignored or grossly underestimated. In some cases, the governments of developing countries, in their headlong rush to modernize, literally commit "ethnocide" by terminally disrupting societies that have been stable for decades. This lack of foresight is

due to the fact that the measurement of 'quality of life,' both in static and rapidly-changing situations, is the most intractible of exercises. Any measurement ot these intangibles is arbitrary in its standards of quantification and generally non-reproducible in its results. Because of the many degrees of uncertainty and the other great difficulties involved in this process, many study teams choose to commit Yankelovich's 'suicide' by delibarately ignoring the adverse environmental and sociological impacts of large water resource projects, especially in developing countries.

Despite these considerable difficulties, it is still necessary to assess, at least in an approximate fashion, the environmental and sociological impacts of project construction, if only to ensure that one or more groups of individuals do not bear a disproportionate share of the burden. It is vital to keep the welfare of the people in mind, particularly in rapidly-developing countries which may possess unstable governments and economies.

The Bottom Line.

The basic problem may be summarized quite succinctly. Hundreds of large water resource projects have been constructed in developing countries. In each case, the decision to build the project has been made. The decision regarding which configuration to construct has been made. In order to make these decisions, some process has occurred by which the social and environmental impacts of a large project have been evaluated – or ignored.

This dissertation blends the sociologist's art and the engineer's science by setting forth a method by which the magnitude of a project's

social and environmental effects may be compared to the magnitude of its purely economic impacts so that the decisionmaker(s) may have a more complete picture with which to make a choice regarding project advisability and configuration.

LITERATURE REVIEW

Introduction.

There exists a vast body of literature dealing with the evaluation and planning of water resources. Numerous excellent texts deal specifically with the evaluation of the tangible impacts of a multiple-purpose water resources project. Others address single project purposes in detail, and still others deal primarily with the quantification of intangible impacts. There are also literally dozens of environmentally-oriented books of value to a water resources planner, many of which deal with the problems of fish passage and water quality. Some of the more complete and useful texts are briefly summarized below.

Water Resource Planning and Economics.

(1) Buras, Nathan. Scientific Allocation of Water Resources. New York: American Elsevier, 1972. 206 pages.

A general-interest text which introduces the engineer or planner to linear and dynamic programming as applied to water resource systems and projects. Also discusses one- and multi-dimensional allocation processes and optimization in space and time.

(2) Garstka, Walter U. Water Resources and the National Welfare. Fort Collins: Water Resources Publications, 1978. 635 pages.

This is an exceptionally complete guide to the purely technical aspects of water resource planning: hydrology, fluid mechanics, statistics, sedimentation, evapotranspiration, limnology, land use and water law are just a few of the subjects covered in this impressive work.

(3) Goodman, Alvin S. Principles of Water Resource Planning.
Englewood Cliffs: Prentice-Hall, 1984. 563 pages.

As one of the finest water resource planning texts in existence, this volume directs the reader through a typical planning sequence: basic economic and financial principles, risk and uncertainty, demographic data gathering, plan formulation, preliminary project evaluation, public involvement, and a short section on the social and environmental effects of project construction.

(4) Grigg, Neil S. Water Resources Development. New York:
McGraw-Hill, 1985. 328 pages.

This author stresses the effects of politics on water resource planning. The book is also distinguished by its chapters on financial planning and organizing for effective water resource planning.

(5) Haimes, Yacov Y. Hierarchical Analyses of Water Resources
Systems. New York: McGraw-Hill, 1977. 478 pages.

A comprehensive guide to systems engineering concepts applied to water resource projects. Highly technical sections on optimization, system identification, multiple objectives, and hierarchical modeling. This volume should prove useful for the state-of-the-art modeler.

(6) Hall, Warren A., and John A. Dracup. Water Resources Systems
Engineering. New York: McGraw-Hill, 1970. 372 pages.

This book is valuable because it applies basic systems science concepts to water resources planning. It includes information on how to define systems and subsystems, objectives, inputs and outputs, and how to 'optimize' decisions and time investments correctly.

(7) James, Douglas, and Robert R. Lee. Economics of Water
Resources Planning. New York: McGraw-Hill, 1971. 616
pages.

An excellent basic text on the technical economic details of water resource planning. Subjects covered in some detail include engineering economy, microeconomics, benefit-cost analysis, and economic planning by project purpose: flood control, drainage, water supply, hydropower, navigation, water quality, recreation, and fish and wildlife enhancement. Also includes sections on cost allocations, financial feasibility, and multiobjective planning.

(8) Howe, Charles W. Benefit-Cost Analysis for Water System
Planning (American Geophysical Union Monograph No. 2).
Baltimore: Publication Press, 1971. 143 pages.

Very useful discussions on the accounting stance, multiple-objective planning, and the measurement and comparison of economic efficiencies over time. Also sections

on project selection criteria.   Case studies are included as
a separate chapter.

(9) Kuiper, Edward. <u>Water Resources Project Economics</u>. London:
Butterworths, 1971. 447 pages.

A text which addresses general concepts; light on hard
numbers and formulas.   Defines planning objectives, gives
basic information on economic criteria, tangibles and
intangibles, and cost allocations.   A very useful chapter of
this book outlines and describes the components of
feasibility reports.

(10) Loucks, Daniel P., Jerry R. Stedinger, and Douglas A. Haith.
<u>Water Resource Systems Planning and Analysis</u>.   Englewood
Cliffs: Prentice-Hall, 1981.   559 pages.

A very general text that deals with the basics of water
resource planning and modeling.   Sections on planning and
analysis,   plan   formulation,   uncertainty,   objective
definition,   and   deterministic   and   stochastic   modeling   of
river basins.

(11) Maass, Arthur, et.al.   <u>Design of Water-Resource Systems</u>.
Cambridge: Harvard University Press, 1962.   602 pages.

Although a quarter-century old, this book lends valuable
insights   into   the   unchanging   basics   of   water   resource
planning: objectives,   basic   economics,   graphical   models,
multiple-purpose project analysis, and the politics of river
basin development.

(12) Major, David C. <u>Multi Objective Water Resource Planning</u> (Water
Resource Monograph 4).   Washington: American Geophysical
Union, 1977.   81 pages.

Subjects   of   interest   include   procedures   for   defining
national and regional objectives in developing countries, and
pricing and cost-sharing.

(13) O'Laoghaire, D.T., and D.M. Himmelblau. <u>Optimal Expansion of
a Water Resource System</u>.   New York: Academic Press, 1974.
273 pages.

As its name implies, this book primarily addresses the
formulation and solving of the optimal expansion problem in
terms of the most efficient allocation of resources.   It
includes a very interesting and detailed example problem, a
rarity among books of this type.

(14) Peterson, Margaret S. <u>Water Resource Planning and Develop-
ment</u>. Englewood Cliffs: Prentice-Hall, 1978.   311 pages.

The most useful portion of this book is the first
chapter, which deals with levels, phases, and objectives of
planning water resource projects.   The remainder is written
from the viewpoint of a Federal government planner, but is

still of interest to those seeking information on general planning concepts.

(15) Saha, Suranjit K., and Christopher J. Barrow (eds). River Basin Planning: Theory and Practice. New York: Wiley and Sons, 1981. 357 pages.

This work addresses the socio-economic and environmental issues related to general river basin planning, and includes some case studies. The general principles outlined in this book are of great value to the technically-oriented planners of any large water resource project, domestic or abroad, by presenting other perspectives in a readable form.

(16) Wiener, Aaron. The Role of Water in Development. New York: McGraw-Hill, 1972. 483 pages.

Basic planning approach for developing countries. Meta-planning, selection of long and short-range goals, transferability and redesigning of models to fit river basins in developing countries, formal and informal power hierarchies, typical development sequences, water resource subsystem analysis, and the definition of management space.

Social and Environmental Impact Assessment.

(1) Andrews, Wade H., et.al. (eds). The Social Well-Being and Quality of Life Dimension in Water Resources Planning and Development. (proceedings of conference, July 10-12, Logan, Utah). Washington: Office of Water Resources, 1973. 221 pages.

This is a varied and somewhat useful collection of papers that deal with quality of life impacts brought about by the construction of domestic water resource projects. Some of the papers address the sociological background of quality of life and social well-being considerations. The papers mostly address general concepts, and are conspicuously lacking in detailed "how-to" guidance.

(2) Bell, Milo C. Fisheries Handbook of Engineering Requirements and Biological Criteria (Fish Passage and Development Program). Portland, Oregon: Office of the Chief of Engineers, U.S. Army Corps of Engineers, 1986. 290 pages.

This is a highly technical, richly illustrated 'how-to' manual on fish passage methods by one of the world's leading authorities on the subject. It includes detailed information on the effects of dams on migrant species and fish bypass study procedures and methods.

(3) Goldsmith, E., and N. Hildyard (eds). The Social and Environmental Effects of Large Dams. Wadebridge Ecological Center, 1983. Three volumes; 796 pages.

This three-volume set should be mandatory reading for all water resource planners. The authors delve deeply into the political motivations for constructing large water resource projects that sometimes have a disastrous effect on segments of the populace. Volume II includes very detailed information on many of the possible negative impacts of project construction and operation, and is rich in case studies. The authors overstate their case rather severely, but a reader cannot help but come away with a new respect for the power of large water resource projects to disrupt social and environ- mental systems.

(4) Stanley, N.F., and M.P. Alpers (eds). Man-Made Lakes and Human Health. New York: Academic Press, 1975. 324 pages.
   A varied and detailed collection of articles on specific diseases and other incidents brought about by the building of water resource projects, including filariasis, leptospirosis, and schistosomiasis. Projects cussed and discussed include Kariba, the Aswan High Dam, Brokopondo, Volta Lake, and the Ord River Dam in Australia.

Public Involvement.

(1) Creighton, James, Jerry Delli Priscoli, and C. Mark Dunning. Public Involvement Techniques: a Reader of Ten Years Experience at the Institute for Water Resources (IWR Research Report 82-R1). Fort Belvoir: Institute for Water Resources, U.S. Army Corps of Engineers, 1983. 494 pages.
   This is an outstanding treatise on public involvement, written primarily from the public's viewpoint. The book stresses public values, communication techniques, and thought processes. All of the details of public involvement are covered, including the identification of the various "publics," research techniques, and methods for conflict resolution.

(2) Fazio, James R., and Douglas C. Gilbert. Public Relations and Communications for Natural Resource Managers. Dubuque: Kandall/Hunt, 1981. 221 pages.
   General principles and procedures for establishing a viable program for effective public/agency communications.

(3) Howell, Robert E., Marvin E. Olsen, and Darryl Olsen. Design- ing a Citizen Involvement Program: A Guidebook for Involving Citizens in the Resolution of Environmental Issues. Corvallis: Oregon State University, 1987. 178 pages.
   Describes a model citizen involvement program (CIP) and case studies that can be used by local and national governments to involve citizens in the decisionmaking process regarding environmental issues that are raised during the

planning process for a large hydroelectric project. Although the CIP is primarily oriented toward a hydro project in the United States, the basic principles should be transferable to most large water resource projects all over the world.

(4) Institute for Participatory Planning. _Citizen Participation Handbook._ Laramie: IPP, 1978. 167 pages.
Addresses the design, administration, and budgeting of an effective citizen participation program. Although the book deals with big and complex projects such as shopping malls in the United States, most of the public involvement techniques described are transferable to water resource planning in developing countries.

Proceedings - Water Resource Planning Conferences.

(1) American Society of Civil Engineers. _Proceedings, Conference on Interdisciplinary Analysis of Water Resource Systems_ (conference held at the University of Colorado at Boulder, June 19-22, 1973). ASCE, 1973. 402 pages.
These proceedings include numerous papers which address interdisciplinary study procedures and the modeling of large reservoirs, rivers and streams. This volume includes several case studies, which allow insight into basic systems science concepts as applied to water resource systems.

(2) Haimes, Yacov Y., and David J. Allee (eds). _Multiobjective Analysis in Water Resources_ (proceedings of the conference in Santa Barbara, November 14-19, 1982). New York: American Society of Civil Engineers, 1983. 239 pages.
An excellent and useful collection of papers which address, among other topics, tradeoffs, implementation, multidisciplinary cooperation, communication, and decisionmaking, components and application of multiobjective analysis, and uncertainty.

(3) International Water Resources Association. _Proceedings, III World Congress on Water Resources_ (8 volumes). IWRA, Mexico City, 1979. 4,116 pages.
This voluminous international collection includes many papers on the multiobjective management of water resources in large river basins, systems analysis in decisionmaking, and multiobjective decision analysis. These papers include basic concepts and viewpoints on systems analysis not ordinarily found in other sources.

(4) _River Basin Development: Policies and Planning_ (proceedings of the United Nations Interregional Seminar at Budapest, September 16-26, 1975). New York: United Nations, 1976. Two volumes, 508 pages.

This is a very valuable compendium of papers, logically ordered to present many facets of planning river basin development in developing countries. The sessions address economic growth, decisionmaking and post-construction evaluation, from the viewpoint of planners from developing countries.

(5) Water Development and Management (proceedings of the United Nations Water Conference at Mar del Plata, Argentina, March 1977). Oxford: Pergamon Press, 1977. Four volumes, 2,775 pages.

Some of the more than one hundred papers presented in this conference are of interest to the water resource planner. Virtually every aspect of the planning process is covered.

Engineering Probability and Statistics: Basic Texts.

(1) Devore, Jay L. Probability and Statistics for Engineers and the Sciences. Monterey: Brooks/Cole, 1982. 332 pages.

(2) Hald, A. Statistical Theory with Engineering Applications. New York: John Wiley and Sons, 1952.

Summary: Literature Review.

As mentioned above, these books and proceedings represent only a tiny fraction of the information available regarding water resources planning, economics, and engineering. However, these and other texts, even if considered as a body, have two major shortcomings;

(1) although some of the water resource publications listed above acknowledge the need for an integrated planning approach, none specify a method for combining the relative magnitudes of economic, social, and environmental impacts of a water resource project into a single indicator for the purposes of assisting decisionmaking.

(2) none of the above water resource texts apply their specific guidance to a detailed and cross-referenced step-by-step example analysis. Usually, case studies are removed to a separate chapter and describe the planning process only in the most general of terms. Specific analysis techniques applied to a step-by-step analysis would greatly aid in understanding the multidisciplinary water resource planning process.

In summary, there is no single unified source that decribes in detail the necessary components of a complete and socially-responsible cost-benefit analysis, and then applies these principles to a comprehensive example problem. This study seeks to remedy this omission.

STUDY OBJECTIVES AND ORGANIZATION

General Objective.

The general objective of this dissertation is to blend the sociologist's art and the engineer's science by presenting a simplified method for accounting for both the tangible and intangible impacts associated with the construction and operation of a large water resource project. This discussion parallels an example analysis of the proposed Three Gorge Dam on the Yangtze River in the People's Republic of China. Table I outlines the body of the dissertation itself, and the remaining sections of this chapter include a general description and outline of the methodology used to derive the final Three Gorge project impact curves.

CONTRIBUTIONS OF THE STUDY

Overview.

Currently, the most popular means of determining a project's economic feasibility (or lack thereof) is a commercial cost-benefit analysis. The body of available literature notes the many deficiencies of this method of project assessment, but does not offer an integrated solution to these problems. This dissertation will contribute to the existing body of knowledge in several critical areas by presenting a unified and simplified benefit-cost analysis procedure.

TABLE I

DISSERTATION ORGANIZATION

SECTION 1 (Chapters I, II, and III)

* Statement of the problem
* Literature review
* Study objectives
* Selection of the study subject
* Introduction to the problem
    * the shortcomings of conventional cost-benefit analysis
    * description of 'quality of life' changes brought about by
        the construction of a large water resource project
* Description of Linestone's multiple perspectives
* Suggested additional perspectives
* Description of the suggested method for combining all impacts
    in order to produce a single indicator of project feasibility
* Background on the Chinese political and planning system, inclu-
    ding a brief treatment of the personal and organizational
    perspectives.

SECTION 2 (Chapters IV, V, VI, and VII)

* A purely economic assessment of each of the major benefits and
    costs of the Three Gorge project, including flood control,
    hydropower, irrigation, navigation, and recreation benefits,
    and relocations and construction costs.
* An assessment and weighting of each probable Three Gorge pro-
    ject social impact
* Evaluation and weighting of probable environmental impacts of
    Three Gorge Dam and Reservoir construction and operation
* Description of the method used to combine these three evalu-
    ations into a single indicator of project feasibility
* A summary of the study, conclusions regarding a range of
    optimum dam heights and reservoir elevations, and
    recommendations.

SECTION 3 (References and Appendices)

* References cited
* A description of the Yangtze River basin
* An outline of the separable costs-remaining benefits (SCRB)
    cost allocation procedure
* General outline of project consequences
* Conversion factors

Methodology Outline. The general purpose of this dissertation is to describe a method for evaluating the relative magnitude of the economic, sociological, and environmental (ES&E) consequences of a water resource project with a single feasibility indicator. The great advantage of this method is that it allows the decisionmakers to weight the various impacts of the project according to their attitudes and values. This will assist the decisionmaking process by insuring that all project benefits and costs are at least recognized and roughly quantified in some manner. This process is accomplished in five primary iterative steps, described below;

Step 1 (Chapter III).
        Research the economic, social, and environmental background
            of the area in which the project under study may be
            constructed. Gather pertinent technical, demographic,
            sociologic, and environmental information.
        Subtasks.
            Identify clients and decisionmakers and their objective
                functions; special interest groups, governments, cities,
                Provinces, Communist Party, individuals, financing
                organizations, public(s)
            Define the system(s), taking into account the;
                * large numbers of subsystems
                * nonlinear input/output relationships
                * competing and nonsynergistic nature of the project
                    objectives
                * limits of risk and uncertainty
                * noncomparable objective functions
                * continuous changes in system components, goals,
                    relationships, objective functions, and decision-
                    maker preferences
            Assemble and train the study team;
                Physical Sciences - meteorology, hydrology, hydraulics,
                structural design
                Social Sciences - anthropology, economics, sociology,
                psychology, languages, politics, law
                Environmental Sciences - fish and wildlife biologists,
                limnologists, entomologists, geologists, and others
            Create or adapt models for use in studies
                * perform complete conventional and unconventional model
                    inventory

   * insure correct basic assumptions
   * balance use of models and personal experience
   * insure proper communication between modelers and users
   * insure model transferability
   * insure model use by proper disciplines
   * inventory model capabilities and limitations
   * verify and calibrate models

Step 2 (Chapter IV).

Derive a dimensionless net economic impact curve. Chapter IV describes a standard commercial benefit-cost analysis modified by the author for the purpose of streamlining the project selection process. The objective function for this study is net monetary benefits.

Subtasks.

Calculate flood control net benefits
Calculate hydropower net benefits
Calculate navigation net benefits
Calculate irrigation net benefits
Calculate recreation net benefits
Calculate construction investment costs
Calculate other benefits and costs
Combine all benefits and costs into a single net economic efficiency curve

Step 3 (Chapter V).

Derive a dimensionless net social impact curve. Chapter V uses multiple perspectives to examine the social impacts of large water resource projects in developing countries. The objective function of this study is net social welfare changes.

Subtasks.

Estimate permanent relocations and upstream and downstream temporary relocations
Estimate the number of lives saved by project flood control operations
Estimate other positive and negative social effects
   * simplified access to irrigation water, drinking water, and navigation
   * irrigation costs: land waterlogging and salinization
   * possible changed incidence of disease
   * fatalities during project construction
   * provision of household lighting and heating
   * many other effects as described in Chapter V
Assign relative weights to intercategory effects
Derive net project relative social impact curve

Step 4 (Chapter VI).

Derive a dimensionless net environmental impact curve. Chapter VI uses multiple perspectives to examine the environ-

mental impacts of large water resource projects in developing countries. The objective function for this study is net environmental quality changes.

Subtasks.

Evaluate project effects upon migratory and resident fish
Evaluate project effects upon wildlife and waterfowl
Evaluate project effects upon insect life
Evaluate project effects upon waterborne plants
Evaluate project area effects
* induced seismicity
* microclimate effects
* estuary effects
Evaluate project effects upon water quality
Evaluate project effects upon air quality
Assign relative weights to intercategory effects
Derive net project social efficiency curve

Step 5 (Chapter VII).

Weight and combine the three curves derived above to form a single indicator of project feasibility. Chapter VII describes an original method for comparing the tangible and intangible impacts of a project by using a common measure.

Subtasks.

Weight the relative economic, social, and environmental net benefit curves
Combine the three relative net benefit curves to produce a total project relative net benefit curve

The entire process described above is executed in two general phases. During the first phase, the ES&E impacts of a project are compared and assigned relative positive and negative dimensionless values within each category. The second phase involves the assignment of relative dimensionless weights to each of the three completed category studies and then summing them to produce a single impact vs. dam height curve for the purpose of assisting decisions about the project.

These two general phases are discussed in greater detail below.

Step 1: Determine the Shapes of the ES&E Curves.

The first step in the procedure is to determine the shapes of the

net economic, social, and environmental impact curves. The shape of the curve is determined by comparing the relative magnitude of impacts within classifications; i.e., how does the effect upon salinity circulation by an altered discharge regime compare in magnitude to the effect of increased food fish production within the reservoir itself?

The shapes of the curves are determined by the dam height/impact magnitude relationships defined in the outline described earlier in this chapter.

Some of the weights of the intracategory indicators could be derived with the use of statistical and probability tools. For instance, Monte Carlo techniques can be employed to determine the possibility of damages and fatalities resulting from serious seismic disturbances caused by the filling of the reservoir and its subsequent operations. Such tools were not employed during this study.

Step 2: Assign Weights to Respective Curve Amplitudes.

This step is the most critical task in the entire planning study, because it assigns weights to all of the work that has been accomplished to this point. The questions that must be answered by the decisionmakers is easy to ask and exceptionally difficult to answer: how important are the combined environmental impacts of the project in comparison with its combined sociological impacts? How important are they in comparison to expected net monetary benefits?

There is no pat formula that may be used to produce answers to these questions for several reasons. To begin with, the three objective functions are entirely dissimilar, and so the decisionmaker's value systems must be applied in order to assign respective weights.

Secondly, there is a great deal of overlap among the ES&E categories.

Curve amplitude is defined as the difference between the lowest and highest values of impact assigned to any dam height for each curve. The respective weighting factors are defined as the factor applied to the amplitude assigned to each impact/dam height curve. Figure 10 in Chapter VII demonstrates how these three dimensionless curves are added in order to derive a single indicator of project feasibility.

Respective ES&E curve weights are assigned based upon one or more of the following factors;

* biases and experience of the decisionmaker(s)
* perceived good to the country as a whole in light of the Four Modernizations
* the relative number of persons affected and the degree of impact upon those persons
* perceived weights that external funding agencies may assign
* inputs by Provinces, cities, special interest groups, and powerful individuals
* interest rates
* relative weight assigned to "O" and "P" perspectives by society
* numerous other indicators, as described in the next three chapters

An example weighting of the economic, social, and environmental impacts of the Three Gorge Dam and Reservoir are given, respectively, at the conclusions of Chapters IV, V, and VI. The final product of the study, a single impact curve, is described in Chapter VII.

Narrowing the Study Focus.

It is the author's experience that, when a large water resource project is being considered for construction, the study team at times becomes 'inundated' with data, and, therefore, must deal with a very

large universe of possible project alternatives. This situation may in many cases cause the expertise and span of control of the study team to be exceeded, bogging down the study, impeding efficiency, clogging lines of communication, and wasting time and money. This dissertation presents a method of using scarce available data to pare the universe of possible project alternatives to a manageable size early in the study, so that the resources of the study team may be expended in the most efficient manner. This method will be particularly useful in developing countries, where indigenous planning expertise and computer hardware and software may be lacking.

Political Influences.

Most of the texts cited in the literature review describe, only in a passing manner, the profound impact of organizations and powerful personalities on the project selection process. It is incumbent upon every study manager and team member to be aware of these forces. An objective of this study is to show how the political process in a developing country (or in a developed country, for that manner) affects the outcome of the project selection process, frequently in defiance of all logic or facts, and often to the severe detriment of small or powerless groups of people. Chapter II notes some of the unforeseen negative impacts of large water resource projects, and Chapter III traces the informal bargaining process used in China over a 50-year period to arrive at a final Three Gorge project configuration.

Decide, Then Study.

The author has written several conventional cost-benefit analyses for the U.S. Army Corps of Engineers. These 'complete' studies,

performed on projects in the $100 million price range, were approximately twenty pages long, and dealt only with the direct benefits and costs of the projects in question. Environmental and sociological impacts were totally ignored or 'handled' by another agency. Public meetings were sparse and perfunctory. In each case, the decisionmaking process on general project configuration was essentially completed before any research into costs and benefits was performed. Although a good beginning, these analyses, in retrospect, were pitifully inadequate. This study has been a learning experience for the author, and, hopefully, it will also give the author's colleagues in Federal water resource planning agencies at least a hint as to the vast complexity and importance of a more complete benefit-cost analysis.

Value of These Study Results.

There are more than fifty separate studies currently being performed on the benefits and negative impacts of the Three Gorge project. Most of these studies are being performed by Chinese entities, and are based on the information provided in the Framework Feasibility Study issued by the Ministry of Water Resources and Electric Power in 1983. Because of the peculiarities of the Chinese water resource planning bureaucracy, these studies are somewhat isolated, conflicting in their conclusions and objectives, and duplicated by other agencies. The only 'unified' study is now being performed by the Canadian International Project Managers. This study will be complete in the summer of 1988. One of the practical objectives of this dissertation is to present, at least in a

preliminary form, a unified study of the Three Gorge project. Numerous agencies have expressed an interest in the results of this study.

SELECTION OF THE STUDY SUBJECT

The subject of this study is the proposed Three Gorge Dam and Reservoir on the Yangtze River in the People's Republic of China (hereafter referred to as 'China'). This project was selected for a variety of reasons.

The Three Gorge Dam is of major interest to civil engineers all over the world. The author is employed by the Power Planning Section, North Pacific Division, U.S. Army Corps of Engineers, which is recognized as an authority on hydropower planning in the Federal government. Members of the Power Planning Section have journeyed to China on several occasions. Numerous foreign engineers have visited the group in Portland, including more than thirty engineers from China, who have visited the Corps for times ranging from one month to one year. These extended visits have provided excellent opportunities for interviews and data collection.

Secondly, no comprehensive benefit-cost analysis or framework study has yet been completed on the Three Gorge project, although numerous agencies in China and elsewhere are currently studying various aspects of the project. The Ministry of Water Resources and Electric Power (MWREP) has produced a Feasibility Study, but no analytical support for a specific project configuration is given. Comprehensive benefit-cost work is now being performed by the Canadian International Project Managers (CIPM), but this work is not complete.

A detailed benefit-cost study for this project is essential, because international lending institutions such as the World Bank and the Asian Development Bank will require such an analysis before lending funds to the Chinese government for the construction of the project.

The age of big-dam construction in the United States is probably over. In order to watch a really large project progress from planning to operation, one must look beyond the borders of this country. Due primarily to its size, the Three Gorge project will have virtually every imaginable class of impact on the surrounding countryside, and its significance is measured in terms of national impact. Because of the project's record size, scores of reports have been written on diverse but strictly limited aspects of the dam. These reports are usually based upon information of widely varying quality and availability.

This dissertation provides an enjoyable and challenging exercise in sorting out which information and assumptions are reliable and which are not, in aid of the final objective: to decide which range of Three Gorge project alternative configurations is most likely to maximize the general welfare of the Chinese people and the country's environment.

CHAPTER II

THE SHORTFALLS OF CONVENTIONAL WATER RESOURCE PLANNING

> Public agencies are very keen on amassing statistics -
> they collect them, add them, raise them to the nth power,
> take the cube root and prepare wonderful diagrams. But
> what you must never forget is that every one of those
> figures comes in the first instance from the village
> watchman, who just puts down what he damn pleases.

— Sir Josiah Stamp

INTRODUCTION

The Diversity of Interests in Water Resource Planning.

The planning, design, construction and operation of a large water resource project requires that many diverse disciplines meet and communicate so that the general welfare of the people may be maximized. Due in large part to the complexity of the planning process and the unique vagaries of every political system, many planning teams overestimate project benefits and fail to properly quantify many of a water resource scheme's most important negative impacts. In exceptional cases, these oversights may cost the lives of many innocent people, as described in some of the case studies in Chapter V.

Overemphasis on the Technical Viewpoint.

These mistakes and omissions are almost exclusively due to the fact that most water resource project planners and managers have a relatively narrow, highly technical background. In many cases, the

planning team may not include sufficient expertise in the identification and quantification of the social and environmental impacts of large water resource projects. Many technically-oriented politicians and project managers also find it difficult or impossible to think in terms of any consequence that cannot be easily 'costed.'

The Value of Multiple Perspectives.

The solution to this problem lies in the examination of the project from several different perspectives. For example, a person skilled in the workings of political systems can readily understand why the High Aswan Dam was constructed in spite of its obvious profound negative impacts on certain segments of the population. And an experienced sociologist will quickly discern why riots occurred during the construction of the Kariba Dam, and why the government was caught unprepared for such a contingency.

Naturally, it is impractical to expect each member of a water resource study team to acquire the skills of a sociologist, psychologist, biologist, attorney, and many other disciplines. However, by carefully examining the consequences of a water resource project from other's points of view - by actually broadening one's day-to-day planning outloook - many otherwise intractible problems may be avoided or resolved to the satisfaction of everyone involved.

This is the purpose of 'multiple perspectives,' as applied to water resource planning. Five perspectives are proposed for application to multidisciplinary water resource problems. Three of these perspectives (technical, personal, and organizational) are described by Professor Harold Linstone in his text, Multiple

Perspectives for Decision Making. So that often-neglected fields of interest regarding large reservoir construction may be given additional attention in water resource studies, the author proposes two additional viewpoints: the social and environmental perspectives. All five of these perspectives are described later in this chapter.

Chapter Outline.

This chapter begins by describing the general nature of the art of water resource planning, and then desribes the five proposed perspectives for examining the various facets of each complex problem. The remainder of the chapter is devoted to describing the shortfalls of standard benefit-cost analyses and the role of uncertainty in planning. The reader is invited to consider how the careful use of multiple perspectives may alleviate many of the planning difficulties caused by uncertainty and a narrow focus on purely technical matters.

THE ART OF WATER RESOURCE PLANNING

The overall objective of any engineering project should be to maximize human welfare. The alternative uses of these resources must be examined over time in order to find the combination that yields the greatest benefits to society. The method most commonly used to assess the economic feasibility of alternative water resource projects, both in this country and elsewhere, is some form of benefit-cost analysis, which is performed by a water resource planning team.

Water resource planning involves more diverse disciplines than any other branch of engineering, because it deals with the most basic of natural resources and human needs. Planning a large water resource project is a vast problem in coordinating the "hard" sciences (hydro-

logy, water quality, groundwater) and the social sciences (law, economics, anthropology). Figure 1 shows the relationship of water resource planning to various science classifications. Water resource planning teams must have expertise in the complete range of theoretical and practical sciences, and just as importantly, they must be capable of communicating not only among themselves, but also with the public.

It is important that each necessary discipline be represented in each water resource planning team. However, it is even more important that each member of the team be capable of seeing the planning process through the eyes of others. This is the great contribution of multiple perspectives.

THE CRITICAL ROLE OF MULTIPLE PERSPECTIVES IN WATER RESOURCE PLANNING

Introduction.

This section describes Harold Linstone's multiple perspectives - technical, organizational, and personal - which are used concurrently to study and understand not only the purely technical aspects of planning, but also the 'behind the scenes' motivations of influential persons and organizations. For the purposes of this study, these viewpoints are supplemented by two additional perspectives - social and environmental - which will be used to lend additional emphasis to often-overlooked project impacts. The characteristics of these five perspectives are described in the following paragraphs.

The Technical ("T") Perspective.

The primary objective of persons using this perspective is quantification. Technically-oriented planners use commercial benefit-cost analyses, hourly production cost models, cost allocations,

ABSTRACT OR
THEORETICAL
SCIENCES

* OPERATIONS
  RESEARCH
* MANAGEMENT
  THEORY

NATURAL SCIENCES

* MATHEMATICS
* PHYSICS
* CHEMISTRY
* BIOLOGY
* HYDROLOGY
* ENVIRONMENTAL

WATER
RESOURCE
PLANNING

SOCIAL SCIENCES

* ANTHROPOLOGY
* ECONOMICS
* SOCIOLOGY
* PSYCHOLOGY
* LANGUAGES
* POLITICS

APPLIED OR
PRACTICAL
SCIENCES

* GEOLOGY
* ENGINEERING
* FINANCIAL
  ANALYSIS
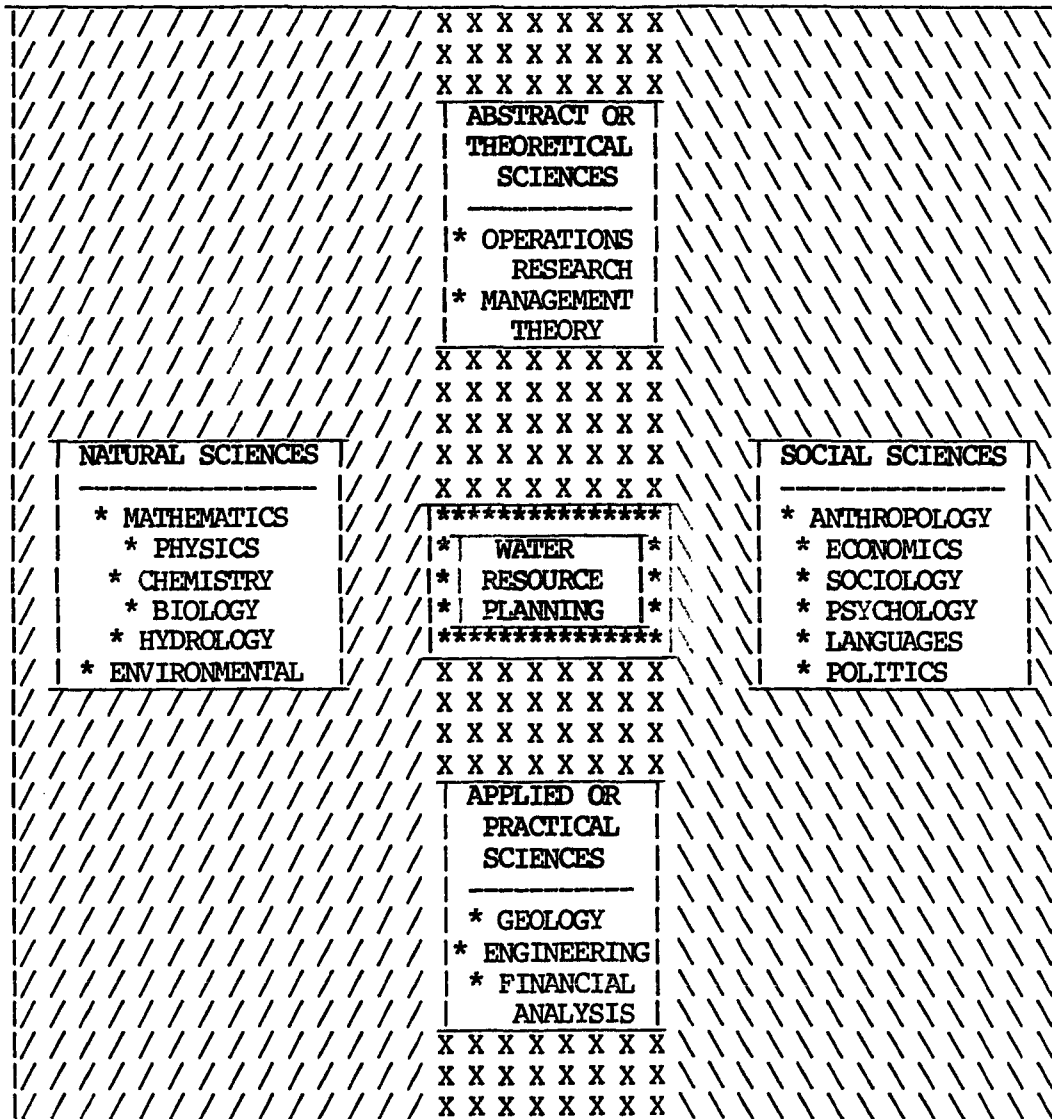
Figure 1. The relationship of water resource planning to the natural and social sciences (modified from Buras). This figure shows the relative positions of various disciplines in the field of sciences that apply in some manner to water resource planning, and the position that water resource planning assumes as it combines aspects of all of these disciplines.

Monte Carlo simulations, and other mathematical and statistical tools to produce a single indicator of project feasibility such as net monetary benefits or a benefit-cost ratio.

Intangibles such as 'quality of life' are either assigned an arbitrary monetary value or are disregarded entirely. This narrow or 'ingrown' outlook leads to profound sociological and environmental difficulties, as described in Chapter V's case studies. Most of the shortfalls of the technical perspective are inherent in the commercial benefit-cost analysis and are described later in this chapter.

Most water resource agencies, ranging from the U.S. Army Corps of Engineers and the Bonneville Power Administration to the Tasmanian Hydro Electric Commission (which has been described as a 'state within a state'), possess a heavily technical perspective, due to the fact that most of their executives are either engineers or economists. This is not to say that the technical perspective does not have a place in the evaluation of water resource projects; to the contrary, it is an integral part of the multiple-perspective concept. However, if it is the only basis upon which a decision is formed, the planning team is inviting disaster from many quarters.

Table II provides more detail on the characteristics of the technical perspective.

The Organizational ("O") Perspective.

The primary objective of this perspective is to lend insight into the inner workings of government agencies and water resource firms and their dealings with other entities. The "O" perspective seeks to dissect the reasoning behind agency decisions by examining their

TABLE II

SUMMARY: CHARACTERISTICS OF LINSTONE'S MULTIPLE PERSPECTIVES

TECHNICAL PERSPECTIVE	ORGANIZATIONAL PERSPECTIVE	PERSONAL PERSPECTIVE
<---- Ethical Basis ---->		
Rationality	Justice and fairness	Morality
<------ Goals ------>		
Problem solving	Stability Maintain status quo	Prestige, status
<----- Discount Rates ---->		
Small	Moderate	Large
<----- Time Concepts ----->		
Technological time	Social time	Personal time
<---- Planning Horizons ---->		
Long distance Narrow breadth	Intermediate distance Intermediate breadth	Short distance Variable breadth
<- Tools Used in Inquiring Systems ->		
Modeling; abstraction "Hard" data	Adverserial, consensual negotiation	Intuition/learning Body of experience
<-- Communication Methods -->		
Technical report Formal briefing	Conference/interview Directive Insider's language	Stories/anecdotes Discussion Speech
<------ Constraints ------>		
Cause and effect Reproducibility Objectivity critical Simplify problems by limiting variables and relationships	Loyalties, favors Insiders/outsiders Political expediency Policical agenda Problem delegation/ avoidance/parceling	Hierarchy of needs (security, acceptance, fulfillment) Challenge/response Subjectivity
<-- Other Characteristics -->		
Optimization Prediction Quantification Tradeoffs Averages, probabilities Uncertainties with many caveats	Planning/SOP's Satisficing Slow, incremental change Compromise/bargaining Uncertainty avoided Fear of error (safe-fail)	Creativity/imagination Narrow span of control Biases/prejudices Fear of change and unknown; need for certainty

motivations and viewpoints. The technical perspective, by itself, cannot hope to untangle the complex interplay between agencies, departments, special interest groups, architectural/engineering firms, and members of the public.

It is an unfortunate fact that many large water resource projects, both in the United States and overseas, are constructed in spite of overwhelming and well-founded opposition. In fact, United States projects with a benefit-cost ratio of as low as 0.18 have been constructed for political reasons. In developing countries, some projects have been built on the strength of a raw benefit-cost ratio, and profound secondary and intangible impacts have been studiously ignored. The "O" perspective lends insight into the political motivations behind these seemingly illogical actions.

Table II provides more detail on the characteristics of the organizational perspective.

The Personal ("P") Perspective.

This perspective examines the impacts that powerful personalities may have upon the decisionmaking process. Nontechnical tools such as intuition and indefinable personal heuristics born of long experience may partially explain decisions that fill gaps in available knowledge or other courses of action that cannot otherwise be explained.

The "P" perspective allows us to examine the personalities, attitudes, and political leanings of powerful persons who influence decisions in indirect but profound ways. For example, Chapter III describes the interplay between the two primary opponents in the debate over Three Gorge Dam: Lin Yishan and Li Rui. The opinions of these

men influenced the outlooks of Mao Zedong and Zhou Enlai, who in turn decided what courses of action to take regarding the Three Gorge project.

The construction and operation of various water resource projects have frequently caused severe human suffering and damage to the environment. In certain cases, planners and government agencies make a conscious decision to ignore or inadequately compensate for this damage. This uncaring attitude is certainly not enshrined by organizations in Standard Operating Procedures or written directives. The answer to why social and environmental impacts are ignored may usually be found by examining the background, experiences, and biases of the decisionmaker(s).

Table II provides more detail on the characteristics of the personal perspective.

The Supplemental Perspectives.

General. This study introduces two new perspectives whose purpose is to supplement the technical, organizational, and personal viewpoints. These two additional perspectives are not general in nature like Professor Linstone's. They are narrow in scope and are meant to lend emphasis to those areas which are most commonly neglected or underestimated in a standard benefit-cost analysis: social and environmental impacts.

The social and environmental perspectives are used to construct a framework for project evaluation in Chapters V and VI. A sixth perspective, which might be labeled the 'economic' viewpoint, is not

necessary in Chapter IV, because it would be very similar to Professor Linstone's "T" perspective.

The Sociological ("S") Perspective. The sociological perspective represents the viewpoint of social groups (villages, tribes) that will bear a disproportionate amount of the consequences of water resource construction and operation. This perspective is similar in many respects to Prof. Linstone's "O" perspective, but its purpose is to narrow the focus and lend weight to the plight of those groups that are relatively voiceless. Table III describes the basic characteristics of this viewpoint in more detail.

The Environmental ("E") Perspective. The environmental perspective will view the construction and operation of a project from the imaginary eyes of the ecosystem as defined by the Chinese culture. The Chinese view the environment as existing to serve man, and any improvement in man's lot brought about by the modification of nature is by definition an environmental improvement (Chen). Chapter III discusses this attitude in more detail. Of course, others, including international lending institutions, see the role of the environment in a different light.

This perspective is unique and separate from the other four viewpoints, and its basic characteristics are described in Table III.

THE BENEFIT-COST ANALYSIS

The Purpose of a Benefit-Cost Analysis.

The general purpose of any type of benefit-cost analysis is to rank the cost-effectiveness of a set of alternative projects. This is accomplished by attempting to assess all or most of the impacts of each

TABLE III

SUMMARY: CHARACTERISTICS OF THE PROPOSED SUPPLEMENTAL PERSPECTIVES

SOCIAL PERSPECTIVE	ENVIRONMENTAL PERSPECTIVE
<———— Loyalties ————>	
Extended family and village	The special-interest group
<———— Goals ————>	
Upgrading standard of living Improvement of quality of life	Preservation or strictly limited mitigation
<——— Discount Rates ———>	
Moderate	Small, even negative at times
<—— Planning Horizons ——>	
Medium distance Narrow breadth	Very long distance Global span
<— Communication Methods and Venue —>	
Grass-roots Adverserial with authority Limited to indigenous language Stories and anecdotes Speeches Direct action under stress	Extremely variable; ranges from grass-roots to high-level lobbying; arcane language; anecdotes to highly technical Little communication directly with public Direct action under stress
<———— Constraints ————>	
Lack of voice and power Lack of education Ingrown or provincial perspective Political unsophistication	Motivational capability Image has limited appeal Uncertainty; conflicting data Lack of political power
<— Other Characteristics —>	
Nearsightedness Need for certainty Stable and established customs, agriculture, and intratribe and intertribe relationships Least multiperspective outlook Slow and incremental change	Imagination/farsightedness Sense of 'system' on planetary scale Sensitivity to human/biosphere interaction Most multiperspective outlook

alternative in order to produce a set of criteria (production functions) which will indicate which option produces the greatest benefits to society. The analysis provides the decisionmaker with one of many possible guides to use when selecting the project that will achieve a given group of objectives at minimum cost.

A rigorous analysis must attempt to identify all project consequences, indirect and direct, tangible and intangible, so that a project's feasibility is supported when most or all of its major impacts are accounted for. The project cannot be isolated in an analysis. It must be viewed as an addition to a complex system which may include one or more entire countries. This axiom must be stressed during every phase of a benefit-cost analysis.

Benefit-Cost Analyses in Developing Countries.

The benefit-cost study for a large water resource project in a developing country is particularly important if that country must rely on foreign financing to construct all or part of the project. In the case of the People's Republic of China, the government must present a comprehensive analysis consistent with the philosophy of international lending institutions such as the World Bank and the Asian Development Bank, not only to better the chances that a loan will be granted, but also to speed the approval of such a loan.

Numerous economists believe that the Chinese will be compelled to perform a detailed economic analysis similar to those done by the United States Bureau of Reclamation and Corps of Engineers before approaching the international banking community for assistance (Biswas; Moyes; Smil; and Wei). However, these purely technically-oriented

studies often omit important, even vital, intangible project benefits and costs. An improvement upon these 'commercial' cost-benefit analyses is the social analyis, which is described in the following paragraphs.

Commercial vs. Social Benefit-Cost Analyses.

Introduction. A standard or 'commercial' economic analysis usually addresses a problem from a purely technical viewpoint. It generally includes an evaluation of only direct, tangible project consequences. A social benefit-cost analysis improves upon this in that it views all project consequences from a social standpoint. An attempt is made to treat all private and public sector projects uniformly, with all criteria held equal for each alternative. A balanced emphasis is placed upon evaluating both tangible and intangible project benefits and costs.

While a commercial benefit-cost analysis may simply ignore intangible benefits and costs, a social analysis attempts to 'mold' intangibles into a tangible form. A social cost-benefit analysis differs from a commercial analysis primarily as follows (Qayum, 1985);

(1) a commercial study analyzes only those factors that have a market. A social economic study also attempts to take into consideration those factors that have no market and thus must be evaluated indirectly.

Both commercial and social analyses will include the assessment of direct inputs and outputs, which include those benefits and costs which accrue to those groups and persons who put the output of the project to its intended use. Direct benefits, for example, may include the net gain in crop income from a lower-value crop which results because of the elimination of flooding, and the increase in land value when agricultural land is converted to urban or industrial land uses.

A social cost-benefit study differs from a commercial evaluation in that it will also include the impacts of indirect and unaccounted inputs and outputs. Unaccounted inputs are those resources and inputs that are consumed free of charge by the project, but which have value to society, such as scenery, water, air and peace. These inputs may take the form of an increment of depreciation on components of the existing infrastructure, including roads, communications, and industrial facilities. Unintended outputs are the generally negative byproducts of a project that have not been estimated, such as the value of better roads and of air and noise pollution. The project usually cannot control these outputs or dispose of them. There is no perceivable demand for them, but they must be accounted for in a benefit-cost analysis.

More detailed descriptions of these terms are contained in Appendix B of this study.

(2) the purpose of a commercial cost-benefit analysis is typically to select a project which maximizes profits, while a social analysis typically attempts to select a project which maximizes welfare over time.

(3) a social analysis attempts to account for factors that affect society and the well-being of individuals.

(4) commercial analyses evaluate inputs based on market prices, and social analyses use shadow prices when applicable.

The Social Benefit-Cost Procedure.

A standard social cost-benefit analysis is usually carried out in the following sequence (Qayum, 1985). This outline is very much simplified, and does not in any way reflect the iterative nature of every step of the process. However, it does serve to give a general indication of the major tasks involved in this type of analysis.

(1) select a set of alternative courses of action that may be implemented to achieve the desired goals.

(2) estimate direct/indirect and intended/unintended outputs and value them for successive years. Assign values to social goods and production factors.

(3) estimate initial and yearly accounted and unaccounted inputs and value them.

(4) calculate annual benefits and costs and net benefits for each year.

(5) calculate the present value for each alternative (or use other criteria) and select the 'best' project.

(6) the project will yield outputs and will require inputs over a period of many years. These quantities will probably change over time and will have to be dealt with by accounting for risk and uncertainty when evaluating each alternative.

Defining the 'Project' and the 'System'.

In the context of water resource planning, a 'project' may be defined as a set of structures (dams, locks, irrigation canals, transmission lines, etc.) plus nonstructural measures (including conservation), which work together to convert the input - which is the inflow of water - into a useful set of outputs that will support one or more of the following objectives;

* flood control   * water supply
* navigation and transportation   * water quality
* irrigation   * fish and wildlife
* hydropower   * low flow augmentation
* disease and vector control   * recreation and tourism
* political re-election   * international prestige

In order to assess the benefits and costs of a project, the 'system' in which it will be constructed must also be defined. Will the project be a small single-purpose hydropower plant that will supply electricity to a mill, with immediate return of water and minimal environmental impact? Or will it be an enormous project such as the Three Gorge Dam, which will profoundly alter the course of a large country's economy?

A large water resource project will exert significant influence on a sizable segment of society. Since it is physically impossible to

model all possible interactions, the system must be isolated from the metasystem in such a manner that the remaining portion of the system under study is manageable in size and complexity. The impacts of any important deleted relationships with the metasystem must be expressed in a simplified form and incorporated into the analysis.

For the purpose of this study, the 'system' in which the Three Gorge Dam will operate is defined as that area which receives a certain defined degree of benefits or suffers a certain degree of adverse impacts due to the project. This area will vary, depending upon which benefit or cost is being examined. The system relating to each benefit or cost will be defined in Chapter IV, which deals with the economic evaluation of the various categories of project benefits and costs.

THE SHORTFALLS OF THE STANDARD BENEFIT-COST ANALYSIS

Introduction.

A 'standard' commercial benefit-cost analysis is frequently the main document used to support the economic feasibility of a water resource project, particularly in a study done by a United States entity. The use of a straight dollars-and-cents assessment of direct monetary (tangible) benefits might be perfectly satisfactory for those small projects whose impacts are strictly limited to an easily-defined area, such as a 100-kilowatt hydro plant which would supply the electrical power needs of small isolated homes or industries. It is certainly not adequate for major multiple-purpose projects whose impacts are felt by thousands of persons.

Historical Errors in the Evaluation of Tangible Consequences.

The evaluation of tangible project consequences for even a large

project might seem a simple task, since the degree of uncertainty involved would appear to be relatively low. However, experience has shown that this is not the case. Commercial benefit-cost analysis is subject to inadvertent and intentional abuse and oversights in the valuation of tangible consequences, which frequently causes an analysis to be extremely inaccurate. Table IV lists some of the areas in which errors may be made in the evaluation of tangible benefits.

Examples of such errors abound, both in this country and overseas. A recent study of more than 100 United States Bureau of Reclamation projects showed that more than three-quarters of the projects exceeded their projected adjusted costs by an average of 78 percent (Nelson). It is interesting to note that only four of these projects were constructed within budget. Not only are costs often underestimated, but benefits are overestimated with alarming frequency. For instance, economists assigned large benefits to the pumpback capability of the U.S. Army Corps of Engineers' 160-megawatt Harry S. Truman Dam in Missouri. Planners did not foresee paddlefish mortality problems, which resulted in the abandonment of this feature of the project's operation. The benefit-cost analysis and cost allocation for this project are being reworked at this time, and it appears doubtful that the construction cost of the dam can be supported by its benefits when the pumpback operation is omitted from the analysis.

Sources of Error in the Evaluation of Intangible Consequences.

General. The benefit-cost analysis is a valuable tool for decisionmaking, but it can only provide part of the basis for a

TABLE IV

COMMON HISTORICAL ERRORS IN THE EVALUATION OF TANGIBLE
WATER RESOURCE PROJECT BENEFITS AND COSTS

Costs Underestimated

* construction
* historical and archeological resource preservation
* relocating rural indigenous tribes and persons
* operation, maintenance, and replacements (OM&R)
* transmission facilities
* drainage systems for irrigation projects to prevent soil
  waterlogging and salinization

Values Underestimated

* the prevailing interest rate (for benefits only, thereby
  increasing their present-worthed value)
* farmland lost to reservoir filling (and associated tax losses)
* loss of business to local farm industry
* forest resources lost to reservoir filling
* recreation at nearby existing lakes
* lost recreational opportunities caused by project construction

Parameters Underestimated

* introduction potential and growth rate of endemic diseases
* construction time (and therefore interest during construction)
* reservoir sedimentation rate
* salinization and waterlogging of land
* sociological impacts upon persons to be relocated
* reservoir evaporation, transpiration and seepage rates
* induced seismicity caused by undetected geologic instability

Values Overestimated

* the prevailing interest rate (for costs only, thereby
  decreasing their present-worthed value)
* jobs created by the construction and operation of the project
* flood control benefits, by overestimating future downstream
  development
* irrigation benefits, by overestimating future crop values

Parameters Overestimated

* project lifespan
* recreational visitation rates
* population, navigation, irrigation and industrial growth rate
  projections

decision because it is an economic model with all of the shortcomings inherent in any model. Most importantly, it can only represent the real world in an imperfect manner. As described above, even the assessment of tangible project consequences often goes awry. It is not difficult to imagine the great potential for error when evaluating intangibles. Some of the major variables which interfere with the assessment of intangibles by introducing uncertainty are described in the following paragraphs.

Value Systems. The value systems of the analysts and the decisionmakers, who are products of their background and training, have . a profound impact on the selection of a project alternative. At certain times, the decision may be predictable to some extent, as in the debate between Li Rui and Lin Yishan regarding Three Gorge Dam.

It is almost axiomatic that the persons in charge of the planning, design, and construction of large water resource projects, both in developed and developing nations, are the product of a highly technical background. These engineers and managers are expert in the so-called 'hard,' or mathematics-based sciences, such as hydraulics or embankment design. However, they usually have little or no training or expertise in the legal, environmental, and social impacts of large projects.

Engineers with a purely technical perspective dominate the planning and decisionmaking processes in almost every water resources agency in the world. This virtually guarantees that the environmental and sociologic effects of large projects will be glossed over or paid lip service (Bandyopadhyay, Dogra). Other problems are the lack of

coordination with those affected by the dam, overstatement of benefits, and understatement of costs.

This domination of the planning process by technical personnel caused problems for the author during the process of gathering information about the Three Gorge project from Chinese visitors to the United States. Table V lists the names and positions of the Chinese engineers and scientists the author interviewed. The background of these gentlemen is almost purely technical in nature.

This technical bias facilitated the gathering of technical information on the physical features of the Three Gorge project. To some extent, it also allowed a free exchange of ideas and opinions regarding the structure and relationships of Chinese water resource agencies. However, information regarding the evaluation of the sociological impacts of project construction was almost impossible to obtain through interviews.

In summary, any type of benefit-cost analysis has inherent problems, no matter how comprehensive or 'impartial.' The analyst, by assigning a dollar value to intangibles, must assign his values, not those of the decisionmaker. The emphasis is placed on producing a single indicator of project worth (dollars). This means that a large portion of the decision, if not all of it, is made by the analyst, not by the decisionmaker.

The Quantity of Available Information. During the study of a large water resource project, it is physically impossible to accumulate enough information to make a perfectly reliable decision regarding which of many alternatives will be 'the best.' Although some may

TABLE V

INTERVIEWS CONDUCTED WITH CHINESE SCIENTISTS AND ENGINEERS

Ministry of Water Resources and Electric Power

Dong Xuecheng, Deputy Chief Engineer, Yangtze Water Conservancy and Hydroelectric Power Research Institute, Yangtze Valley Planning Office (YVPO)

Huang Shaoying, Principal Engineer, Technical Division, Mid-South Design Institute for Hydroelectric Projects

Luo Chengguan, Deputy Division Chief Engineer, Yangtze River Water Conservancy Commission, YVPO

Shang Ke, Chief, Hydromachinery Section, Kunming Hydroelectric Investigation and Design Institute

Xu Yixin, Project Design Division Chief Engineer, YVPO

Xue Shiyi, Deputy Chief Engineer, Planning Division, YVPO

Wei Tingcheng, Commissioner, YVPO

Zhang Dazhi, Chief, Science and Technology Cooperation Branch, Foreign Affairs Division, YVPO

Ministry of Communications

Shi Heng, Deputy Chief of the Navigation Leading Group for Three Gorges Engineering

Tu Qiming, Office of Engineering, Navigation Office, Three Gorges Engineering

Wan Qingquan, Deputy Director, Navigation Office for Three Gorges Engineering, Yangtze River Shipping Administration Bureau

Wu Renchu, Office of Engineering, Navigation Office, Three Gorges Engineering

Zhang Qi, Director, Inland Waterways Transportation Bureau

Captain Zhou Ningbao, Deputy Director of Safety Administration Office, Changjiang National Shipping Corporation

Other Chinese Water Resource Agencies

Cheng Liangjun, Chairman, Yangtze River Hydroelectric Equipment Research and Development Center

Gu Wenshu, Water Resources and Hydropower Planning Research Institute, Beijing

Wang Fuyuan, Electric and Machinery Division, China Water Resources and Hydro Power Construction General Corporation, Beijing

Zong Muwei, Hydraulic Engineering Department, Hydraulic Research Institute, Nanjing

disagree, this is not a failure on the part of the study manager. At some point in time, the effort expended to obtain information exceeds the content and value of the information that is gathered.

The Quality of Available Information. Uncertainty is caused by a lack of reliable information regarding an existing situation or alternative futures. Much information simply does not exist, and the study team must extrapolate from available data while working within a vast range of possible alternatives. Fortunately, the limits of what can be accomplished can usually be established early in the analysis by institutional or physical constraints.

Institutional constraints are limits imposed by persons or groups with appropriate authority. As an example, sections of the Grand Canyon would be inundated if the proposed Bridge Canyon Dam on the Colorado River were constructed to its economically optimum height. This would occur only through authorization by the United States Congress - an unlikely event indeed.

If Three Gorge Dam were constructed to its 200-meter height, power benefits from the 1,000 megawatt turbines would far exceed the monetary costs of relocating 1.4 million people. However, this alternative is still considered politically and economically infeasible by many, and has therefore been discarded by the Ministry of Water Resources and Electric Power.

Physical constraints define the limits of what is technologically feasible in various components of a water project. At Three Gorge Dam, several years ago, one of the arguments against the 200-meter alternative was that 1,000-megawatt turbine-generator sets would be required

in order to take full advantage of the available range of head and streamflow. This turbine size, although beyond previous world state-of-the-art, is now being reconsidered in light of recent world technological developments in the field of hydro turbine design and fabrication.

THE ROLE OF UNCERTAINTY IN WATER RESOURCE PLANNING

Forecasting is difficult, especially when it's about the future.

— Orv Bruton

Introduction.

Uncertainty is inescapable. Its two primary sources are lack of information and unreliable existing information. In order to select a project, information about the future must be obtained, and such information is based entirely upon assumptions. As a study team attempts to peer further and further into the future, confidence limits diverge and uncertainty increases until virtually no reliable predictive information is available and forecasting becomes a completely probabilistic exercise. This problem becomes particularly acute when dealing with a huge project like Three Gorge, which has an assumed lifespan of a century and a construction time of nearly two decades.

This lack of ability to anticipate or control uncertainty is the major cause of error in benefit-cost analyses. In addition to those causes previously mentioned, other sources of uncertainty are described below. This is by no means an all-inclusive list.

Uncertainty Caused by the Organization of Water Resource Agencies.

The collecting of reliable and appropriate data may be hindered by

several factors, even if the study manager knows for certain where the information is and has confirmed that it is likely to be reliable (a set of conditions that is extremely unlikely to occur). For example, in the Three Gorge study, the author found that information received from various agencies frequently conflicted. The reasons for this phenomenon are numerous.

One of the factors delaying the final resolution of the conflict over Three Gorge Dam was the profusion of Chinese water resource agencies at every level, their lack of communication, and their conflicting and overlapping areas of responsibility. On September 14, 1979, He Zhi summarized the condition of Chinese water resource planning in one word: "anarchy." He stated that the management of various agencies were "each doing things in his own way," and summarized by saying, "In China, there is no unified management department governing water resources, nor are there any laws" (Biswas, 1983).

This view is somewhat exaggerated - but only somewhat. Contemporary high government officials had seen, under Mao's reign, an undesirable amount of power concentrated in the hands of one man. In today's government, a majority of agencies involved in the planning of a large project must reach agreement, except in very unusual cases. The process of project planning and approval, particularly with the involvement of the Revolutionary Communist Party, can be nightmarishly complicated, and there is inevitably a great deal of infighting and duplication of effort. This is due to the fact that the Chinese have organized their organizations and lines of influence rather like an

Army unit: information and influence flows freely in a vertical direction, but is inhibited severely in a horizontal direction. This guarantees that there will be duplication of effort in studies and conflict over study results when they inevitably disagree.

Another source of uncertainty is the actual ability of the water resources agencies in a developing country to carry out their plans. Long delays in construction time caused by administrative confusion and possible lack of managerial and on-site technical skills will cause interest during construction costs to balloon, particularly in the case of a project with a long construction period.

The Cultural Revolution and subsequent disturbances virtually wiped out technological progress in China during the period 1966 to 1975. Managers, engineers, and intellectuals were ridiculed and restricted in their activities, universities were closed, and technological and managerial exchange with other countries was nonexistent. This decade-long gap means that the pre-Cultural Revolution leaders and managers, the most experienced that China possesses, are now retiring, leaving their leadership roles in science and industry to less-experienced personnel. There is no smooth transition here; the Revolution which began twenty years ago guarantees that there is a significant gap in experience between the old managers and the new.

This raises a critical question: even if the Chinese have the technical know-how to construct the Three Gorge Dam, can they manage the construction and operation of the project?

The answer, gleaned from facts and opinions gathered in more than thirty interviews, appears to be yes - primarily because the Chinese have recognized the problem and have moved to remedy the situation. The Chinese have been agressively pursuing a program of technological exchange with developed countries for several years now, and have accepted that they will probably need outside help in managing the project's construction.

In order to bridge the gap between the old managers and the new, the Chinese are pursuing their technological exchange program with vigor. In fact, training programs are a condition of virtually all significant contracts with China. There are now more than 11,000 Chinese in foreign university engineering and economics programs, preparing for the future (OTA). And, within the last five years, more than a thousand middle- and upper-level managers have had 'hands on' experience with U.S. government agencies and large firms - more than thirty with the Bonneville Power Administration and the North Pacific Division of the Corps, over periods ranging from four weeks to 15 months.

Uncertainty Caused by the the Interview Process.

General. During this study, the author found that the most valuable source of information from the organizational and personal perspectives was the informal interview.

The 'ideal' interview situation involves as its keystone a lasting correspondence with an English-speaking expert from the developing country so that a dialogue is established which will yield the infor-

mation that is required. Admittedly, this type of situation will normally be quite rare for a number of reasons.

Interview Strategy and Format. In some cases, a period ranging from one day to a couple of weeks may be available for interviews. The interview process should be pursued carefully in an informal atmosphere, and no attempt should be made to hurry it along. In this study, the author began by learning as much as possible about the Chinese engineers and scientists who would be staying with the Corps. It helped immensely to be assigned the task of arranging for food and accomodations and driving a van while conducting the Chinese on tours of Northwest hydropower projects. These tours provided the opportunity to be with the Chinese engineers for long periods of time, and facilitated a free exchange of ideas, despite the presence of ten persons at a time.

The strategy and protocol involved in asking questions is critical and requires almost an obsession with detail. In the first few days or weeks of a working or interview-type relationship, personal questions and even queries into the inner workings of Chinese water resource agencies should be studiously avoided, because they may be perceived as prying or intrusive. This information will be volunteered eventually, if the interviewee desires. Questions are instead initially directed towards purely technical matters and the status of the project of interest.

Questions requiring a "yes-no" answer should be avoided, because the answer tends to be "yes" under most conditions. One Corps hydropower engineer, on a 1985 visit to China, asked if he could have a copy

of a river basin wall map that was displayed in a local office of the Ministry of Water Resources and Electric Power. The Chinese engineers assured him that this was possible. Later in the day, he was presented with a rolled-up sheet of paper which he assumed was a copy of the wall map that he desired. Only upon arrival at the airport did he discover that he was the proud owner of a blank sheet of paper!

Critical questions should be asked of several persons, as a means cross-checking. If a single person is being interviewed, questions of interest should be repeated in different terms after several days as a means of confirmation.

The most valuable information the author received was obtained after numerous dinners and other events with individual Chinese engineers which took place over a period of more than six months. The Chinese revealed themselves to have a wry sense of humor, an appreciation of the finer points of United States government bureaucracy, and a love of cooking, among other things. While cooking meals, the Chinese engineers talked at length about their jobs, their families and friends, and their opinions regarding the Three Gorge Dam and the inner workings of the Chinese bureaucracy. Over a period of several months, the author obtained a detailed but rather limited view of the status of Three Gorge Dam.

Translators and Language. The services of a translator may be required when dealing with experts from a developing country. A translator 'strains' information passing from the sender to the receiver through his own filter, adding another degree of uncertainty to the data transfer process.

Under ideal conditions, the person receiving the information from the foreign expert would be a native speaker of the appropriate dialect. Failing this, it is useful to cross-check by having two translators on hand who have a technical background and speak good technical English. The author was fortunate enough to have two such persons with him during many of his interviews.

Even under excellent conditions, a direct translation of information regarding highly technical subjects may be impossible. This would seem to be a particularly acute problem in the biological sciences, but water resources planning is primarily based upon well-known and ancient principles, and the language used to convey ideas can be expressed in simple terms.

Uncertainty Caused by Political Considerations.

It is quite difficult or impossible to predict or model the shifting alliances between political parties, special interest groups, and powerful persons. The situation is like a boiling cauldron of alphabet soup. Observers can only see a small part of what is happening, and what can be seen is constantly changing.

The machinations inherent in politics may lead to the construction of a project whose major purpose is to aid the current regime to stay in power. The people and the opposition are impressed by such displays, which are intended to give a sense of forward progress. The urgent need for power and irrigation waters may cause developing countries to plan and construct "showcase" projects that do not meet the demands of the region or of proper social cost-benefit analysis. These projects may never pay back their construction costs once all of

their social impacts are assessed, usually years after they are completed. Other projects may be wildly successful from a national accounting stance, but disastrous to certain small segments of the population. Outstanding examples of the latter type of project are described in Chapter V.

John Waterbury highlights another source of uncertainty caused by an ingrown bureaucracy - the tendency to avoid accountability whenever possible (Goodman);

> Policy-making groups and external creditors prefer an incomplete picture, for then the unanticipated can be written off to incomplete information and poorly defined responsibilities.
> Planners and policy makers limit their responsibility by limiting their range of vision and by retreating into narrowly defined competences. Sectoral and time horizons are constricted as far as possible. Each specialized agency seeks a closely defined mission and relies upon the information of other relevant agencies in designating targets. If the information is erroneous or not forthcoming and if targets are missed, the blame can be shifted on to other quarters.
> The fact is, that as a rule, the politically determined decision comes first and it is exceedingly difficult thereafter to nurture the informed and dispassionate debate requisite to assessing long-term costs.

Other Sources of Uncertainty.

System Boundaries. At a certain level of interaction, players in the 'system' are necessarily excluded from that system so that the model in use becomes manageable. When these players are omitted, their influence must be accounted for with an approximation.

The Discount Rate. A fluctuation in the cost of money of only one or two percent may make or break a project's economic feasibility.

Additionally, the interest rate applied by private and public sectors may vary substantially.

Construction Costs. The bids submitted by contractors very rarely approximate actual final costs for various reasons. If a project has a particularly long construction time (as in Three Gorge, at eighteen years), this will reflect directly upon interest during construction, which will accumulate quickly, particularly at higher interest rates.

Evolution of the System. The development pattern of the system may change substantially as the project is being planned and built. It is axiomatic that a complicated system evolves from state to state through a series of intervening unstable conditions which are totally unpredictable in nature (Corps, 1981).

The Model. A developing country does not consume inputs and produce outputs in the same manner as a developed country, but the latter have the models. Inappropriate models will have a low predictive value because a project built in a developing country will have a far different set of impacts than the same project built in a developing country.

Interdiscplinary Language Distortions. Because water resource planning is so thoroughly interdisciplinary in nature, many specialized languages are involved, and much information will be altered or lost in translation. Even the most appropriate interdisciplinary language cannot accurately represent the true and complete situation.

Summary.

A properly-executed analysis will consist of rigorous procedures that force the analyst to examine each consequence of a project and the

important interactions between them. However, a selection of the 'perfect' alternative is impossible. The best we can hope to do is improve the lot of as many people as possible while trying to avoid or mitigate unacceptable damages to others.

Benefit-cost analysis is subject to numerous abuses and oversights. However, it is undeniably a valuable tool (but only one tool) for assessing a project's worth. It is not even a necessity in some developing countries. A formal economic analysis for an exceptionally large project may be entirely foregone in a country where the "P" perspective carries little weight, as in China. Although the current configuration of Three Gorge Dam was arrived at after decades of intense debate and infighting, many Western economists doubt that a rigorous benefit-cost analysis would prove their decision regarding the ultimate configuration of the project to be far wrong.

CHAPTER III

BACKGROUND ON THE THREE GORGE PROJECT
AND THE LOWER YANGTZE RIVER BASIN

The individual is subordinate to the organization.
The minority is subordinate to the majority.
The lower level is subordinate to the higher level.
The entire Party membership is subordinate
   to the Central Committee.

— Former Communist Party Chairman
Hua Kuo-Feng

INTRODUCTION

In order to make an informed selection between specific project alternatives, an external decisionmaking body must be familiar with the political processes involved in making decisions. The decisionmakers must also have access to detailed and reliable information regarding the history and water resource needs of the pertinent river basin and surrounding areas.

This chapter provides background on how a process of tradeoffs and compromise in Chinese government agencies over a period of half a century has led to the selection of the current Three Gorge project configuration, and outlines the means by which the lower Yangtze basin might consume specific Three Gorge project outputs such as flood control, hydropower, and navigation. This information serves as a general basis for the calculations and detailed data given in the next

three chapters, which deal with the economic, sociologic, and environmental feasibility of the project.

The Three Gorge Dam and Reservoir is a project without precedent in size, complexity, and impact. For more than three decades, the debate on a high dam in the Three Gorges has raged in China, but general agreement on its configuration - and even on the advisability of its construction - remains elusive.

If one were to examine in a cursory manner the direct benefits and costs of the project, there would probably be no question that the project should be constructed as soon as possible. In fact, it may not at first be apparent why it has not already been built. In order to understand the currents of contention surrounding Three Gorge Dam, it is necessary to first become familiar with some of the pertinent inner workings of certain Chinese planning agencies, and the interactions between these agencies and other entities and individuals.

This chapter explains the basic elements of some of those entities and procedures that exert, directly or indirectly, influence on decisions regarding this project. The roles that certain Chinese water resource agencies, Provinces, counties, and powerful personalities play in the planning process are outlined below in a brief description of the historical debates over the project.

The picture is complicated by fundamental uncertainties: cost and financing, the Chinese economy, and the fact that Three Gorge Dam is world 'state of the art' in virtually every respect. These concerns, which are of utmost importance to many of the 'players' in the history of the project, will be addressed throughout this section.

ECONOMIC PLANNING IN THE PEOPLE'S REPUBLIC OF CHINA

The <u>Central</u> <u>Role</u> <u>of</u> <u>Water</u> <u>in</u> <u>China's</u> <u>Developing</u> <u>Economy</u>

The critical role played by water is one of the outstanding features of China's rapidly developing economy. Before the turn of the century, China in general used little of its vast supply of water for other than agricultural purposes. Much of the people's effort and time went into simply feeding themselves. The production capacity and standard of living of the vast majority of people were quite low.

China's non-industrialized economy was dependent upon its land, which was cultivated intensively but inefficiently in terms of the use of human resources. Agricultural production capacity in the country's Yangtze and Yellow River breadbaskets was at the mercy of drought and flood, and the land yielded only a modest quantity of crops even in good seasons, due to the lack of mechanized power equipment and the low return the farmer received for his goods. Therefore, the nation's agricultural sector was caught in an aggravating and chronic dilemma; it had little capital with which to purchase updated farm equipment, but could not get this capital until production increased. The cycle of low production-low savings-low investment-low income is now slowly being overcome by a program of unified resource development, which are embodied in the 'Four Modernizations.' However, as in other economies, water resource development projects must compete with large projects in other sectors - industry, defense, communication and transportation - for scarce capital.

The <u>Current</u> <u>Status</u> <u>of</u> <u>China's</u> <u>Economy</u>.

The emphasis on each of the "Four Modernizations" (technology,

industry, agriculture, and defense) reflects the Chinese desire to advance economically in a logical, well-planned pattern. As a result, China has made significant progress in construction, foreign trade, and overall individual standard of living criteria. The gross value of agricultural and industrial production is rising steadily at an average annual rate of about ten percent (see Table VI).

Despite these advances, each of the Four Modernizations are advancing at a different pace, primarily due to major national energy and transportation imbalances. Most importantly, a chronic energy shortage has restricted the output of the heavy industrial sector to about 75% of its capacity in recent years (Rawski). This shortage was caused partially by an inappropriate emphasis on heavy industry, which now cannot be fully supported by the energy and transportation systems. This problem has also led to a shortage of many raw materials in the light industrial sector.

Secondly, transportation bottlenecks on land routes are severely limiting the transfer of vital bulk goods in some sectors. The national rail system has reached near-saturation, and more than half of all tonnage shipped is coal (Beijing). This problem is described in a subsequent section of this chapter. Additionally, ports have insufficient capacity to handle the desired volume of foreign trade.

Since 1979, China has actively been seeking an appropriate balance between consumption and investment. The inappropriate emphasis on heavy industry investment is at the root of many of China's economic problems, including personal income and standard of living stagnation from Liberation to the mid-1970's. Perceptions of the great strides in

TABLE VI

PEOPLE'S REPUBLIC OF CHINA
ECONOMIC INDICATORS, 1949-1983

Year	Retail Price Index	National Income	Production ($billions)			
			Industry			
			Light	Heavy	Agricultural	Total
1949			4.9	6.5		
1950			6.6	8.8		
1951			9.3	12.3		
1952			11.5	15.3		
1953			14.6	19.4	62.7	96.7
1954			16.8	22.3	65.4	104.5
1955			17.7	23.5	68.3	109.5
1956			21.3	28.2	71.4	120.9
1957			23.9	31.7	74.5	130.1
1958			35.0	46.3	77.8	159.1
1959			42.5	56.3	81.3	180.1
1960			44.3	58.7	71.1	174.1
1961			26.1	34.6	62.1	122.8
1962			27.5	36.4	70.5	134.4
1963			32.8	43.4	80.0	156.2
1964			39.4	52.2	90.8	182.4
1965			47.8	63.3	103.0	214.1
1966			55.8	73.9	106.7	236.4
1967			48.7	64.5	110.5	223.7
1968			53.6	71.0	114.4	239.0
1969			63.8	84.5	118.5	266.8
1970			75.3	99.7	122.7	297.7
1971	100.0	118.9	81.9	108.5	117.9	308.3
1972	99.8	122.6	87.1	115.9	117.6	320.6
1973	100.4	132.2	96.5	125.7	127.5	349.7
1974	100.9	133.2	98.9	123.9	132.7	355.5
1975	101.1	141.7	113.1	143.3	138.9	395.3
1976	101.4	137.0	114.9	145.1	142.3	402.3
1977	103.4	146.4	130.8	166.3	144.7	441.8
1978	104.1	164.2	145.3	191.9	157.7	494.9
1979	106.2	175.7	159.9	206.0	171.2	537.1
1980	112.6	188.0	195.3	202.4	177.9	575.6
1981	115.2	197.0	201.2	213.1	189.6	603.9
1982	117.5	212.4	216.4	225.2	210.3	651.9
1983	119.5	233.6				

References: Rawski; Bush; Beijing.

material standard of living and 'quality of life' in other countries (notably the United States and Japan) inevitably filtered in to the populace and may have contributed to an enervating effect. China's social policy now includes a commitment to increasing personal income. Indeed, since 1979, real per capita personal income has risen at an average rate of about seven percent annually (Chen, Nai-Ruenn).

Retail prices have been rising moderately since 1978 due in part to a shortage of consumer commodities. Other indirect inflationary effects include failure to meet certain production quotas, inferior product quality in some areas, budget deficits, rationing, government subsidies, and a slight departure from official fixed prices.

Goal Setting with Long-Term Plans.

The political status and viability of a major Chinese water resource project may be partially explained by determining its position in the planning process. The first step in the long process towards construction is to get a project acknowledged as a candidate for a long-term plan. The project must fulfill one or more of the general goals of the long-term plan, which only defines general principles and directions about the size and shape of China's future economy. These principles might be spelled out in a statement of purpose for a cluster of Five-Year Plans or in a program such as the "Four Modernizations."

General objectives may also be formulated in a key slogan, such as the Communist Party's "General Policy" of 1960: "Agriculture is the foundation, industry the leading sector," or "Water conservancy is the lifeline of agriculture" (Nickum).

The areas of emphasis for the Four Modernizations are agriculture, science and technology, industry, and defense. There is no question that the Three Gorge project would advance the causes of both agriculture and industry. Since Dr. Sun Yat-Sun's declarations regarding the project in 1935, Three Gorge has remained one of the projects that is considered for inclusion in each successive Five-Year Plan (FYP). But the jump from being part of a long-range plan to being included in a FYP is enormous, because the major points of contention about a project must be resolved, and because inclusion in a FYP commits significant money and resources for the first time.

Medium-Range Planning with Five-Year Plans.

The Five-Year Plan is the basic building block of a long-range plan. In order for a project to be included in a FYP, it must be generally accepted by most of those involved in the economic planning process by demonstrating without serious question its economic worthiness. If a project is included in a FYP, funds are committed and dates for both construction startup and completion become relatively firm. However, if a major project is not included in a Plan, it is almost a certainty that it will not be started during the implementation of the Plan (Lieberthal).

Peculiarities of the Chinese Statistical System.

A proper project analysis must rely on several basic classes of statistics gleaned from many sources. This task, which includes the reconciling of conflicting sources, is daunting under the best of conditions. However, when dealing with the analysis of a major water resource project in the People's Republic of China, a foreign planner

must use imagination, daring, and experience to fill in the many areas that are virtually devoid of reliable data.

Because of the wildly fluctuating quality of historical data available on the Chinese economy and its energy sector, it is a difficult task to determine exactly how Three Gorge Dam and Reservoir outputs would be utilized in the agricultural and industrial sectors. It is therefore also extremely difficult to support the project's economic feasibility with 'hard' numbers.

Although there are large gaps in the statistical data produced by China, there is no evidence that the numbers are knowingly falsified at the national level for propaganda purposes, for either internal or foreign consumption, since the Cultural Revolution. As Dwight Perkins claims, "No one has produced evidence of the existence of two sets of books," despite the fact that tens of thousands of knowledgeable persons, including many experienced economists, visit the country each year. The problem lies primarily in the fact that, historically, enormous pressure from above may lead to the production of false or midleading statistics from below.

Additionally, there is considerable difficulty in the translation of complex economic terms. For example, the distinction between "heavy" and "light" industry is blurred at most times. Also, most countries include services in output calculations, while China does not (Rawski). Additionally, Chinese economists do not include the values of raw or finished materiel transferred between different sectors or industries, which distorts the gross output index.

Statistical data on most aspects of energy and goods production is of extremely good quality and reliability during the period 1953-1957. Those accrued during the Great Leap Forward (1958-1960) are in many cases highly exaggerated and may include outputs that are of low or unusable quality, i.e., steel from the so-called "backyard blast furnaces."

Following the Great Leap, a statistical blackout endured until Recovery in 1965-1966. Most meaningful statistics disappeared again during the onset of the Cultural Revolution in 1967-1968. For the next decade, some statistics are very fragmentary (Howe, Christopher). Since 1980, statistics are of uniformly better quality and reliability as China attempts to accurately pinpoint the causes of its economic problems.

In a general sense, although official reports on coal and hydropower resources are quite good, comprehensive data on certain important aspects of the Chinese energy program, such as conservation, development and production costs, and fuel conversion efficiencies, are still almost nonexistent (Smil, 1978; Clarke). The little data that is available in these areas must be considered suspect, and a great deal of guesswork and interpolation/extrapolation must be performed in order to produce workable numbers.

The external methods used to estimate economic terms (especially those regarding energy) would fill several large filing cabinets. Fortunately, talented economists from several nations have immersed themselves in the intricacies of converting raw economic indicators to a form that can be manipulated by "standard" means. These researchers

include the Central Intelligence Agency's Dr. Robert Field and the Department of Commerce's J. Aird and Jo Emerson. Since a detailed analysis of the huge mass of available economic data is far beyond the scope of this dissertation, statistics generated by these and other researchers, and by national organizations like the Ministry of Water Resources and Electrical Power, which have a proven record of reliability, are used as the basis for calculations throughout this study.

THE ANSWER TO ECONOMIC STAGNATION: THE "GRAND TWENTY-YEAR PLAN'

The Sixth through Ninth Five-Year Plans.

In 1983, Vice-Premier Li Peng outlined the overall goals of Chinese long-term economic development. He described three areas of emphasis (energy/transportation, agriculture, and education/science), as part of a logical and well-ordered "Grand Twenty-Year Plan," which stands in sharp contrast to the badly-planned and discouraging early FYP's.

Earlier, at the September 1982 National Congress of the Chinese Communist party, former General Secretary Hu Yao-Bang had announced the basic goals for the country's economy through the year 2000 under the Sixth to Ninth Five-Year Plans. The primary objective of the Plans is to quadruple the value of China's annual industrial and agricultural output by the end of the century, from $540 billion to $2,100 billion (Chen, Nai-Ruenn). This will require an average growth rate of seven percent annually.

This impressive figure is not unrealistic. The gross value of China's agricultural and industrial output has increased at a rate of

9.2 percent annually from Liberation to 1981, a span of 31 years, despite frequent internal upheavals (see Table VI). Additionally, the 6th through 9th FYP's differ from earlier ones in that they lay out a logical, well-ordered development process with realistic and moderate growth rate goals based upon solid research and experience missing in earlier Plans. If current economics trends continue, it appears that the basic goals will be met by the turn of the century (Chen, Nai-Ruenn). The 'Grand Twenty-Year Plan' is off to a quick start; economic growth under the Sixth Five-Year Plan nearly doubled the stipulated goal of 4.5 percent annually. If the Seventh FYP merely meets its modest target of 6 percent growth annually, the residual growth rate will only need to be 6.8 percent annually during the last decade of this century.

The First Ten Years: 1981-1990.

The long-term strategy for the Twenty-Year Plan will be executed in two stages, each of ten years' duration. The first stage, to be implemented during the period 1981-1990, consists of the Sixth and Seventh FYP's. This first stage is currently laying a foundation for rapid economic growth during the second stage.

The Chinese government addressed its most basic economic difficulties in the Sixth FYP, which emphasized economic readjustment. Building on this progress, the Seventh FYP will complete basic energy and transportation facilities and will upgrade economic management at the highest levels.

The Sixth Five-Year Plan placed a heavy emphasis on energy and transportation projects. It included the construction of 890 large and

medium projects, many of which were continued into the Seventh FYP.

123 "key" projects were started, including (Chen, Nai-Ruenn);

* 29 "key" projects in the transportation sector, and 46 "key"
    projects in the energy sector,
* 28 new coal mines, each of which will produce at least one
    million tons annually,
* 15 new hydro plants of at least 400 megawatts capacity, and
* 45 new thermal plants of at least 200 megawatts capacity.

Actual expenditures during the Sixth Five-Year Plan were as

follows;

* total capital construction investments - $130 billion,
    including;
    * transportation - $17 billion
    * energy - $33 billion, including;
        * electric power - $12 billion
        * coal processing - $10 billion
        * petroleum - $8 billion
        * energy conservation - $3 billion.

The Second Ten Years: 1991-2000.

Specific details of each Five-Year Plan are generally announced

after detailed planning conferences, which take place shortly before

the Plan is to be put into operation. Therefore, no particulars are

available at this time for the Eighth Five-Year Plan (1991-1995), or

for the Ninth Five-Year Plan (1996-2000).

THE ORGANIZATION OF CHINESE WATER RESOURCE PLANNING AGENCIES

Overview.

Due to the anticipated widespread positive and negative impacts of

Three Gorge Dam, an unprecedented number of Chinese water resource

agencies at every level are involved not only in the decision to build

or scrap the project, but also in the planning and design of its

ultimate configuration. This vast number of players has, at one time

or another, included the Chinese Communist Party, a half-dozen Ministries, several Provinces, numerous cities and counties, and strong personalities such as Zhou Enlai, Mao Tsetung, Li Rui and Lin Yishan.

It is literally impossible to list the great number of agencies, political subdivisions, and persons involved in the planning and design of Three Gorge Dam, primarily because of the paucity of information at lower levels. Still, an understanding of the basic structure and mission of some of the upper-level Chinese agencies that are involved in the planning or construction of the Three Gorge project is essential to an understanding of how the configuration of the dam has evolved through the last five decades.

The following paragraphs will aid understanding of the positions of various entities that are mentioned in the history of the debate. Organizations Involved in Three Gorge Project Planning.

Introduction. Figure 2 shows the working relationship between the Chinese Communist Party and Chinese water resource planning agencies. Many of these entities have exerted significant influence on the evolution of the Three Gorge project. The interrelationships of the agencies, their superior and subordinate units, and information on their leaders are briefly described in the following paragraphs.

The Politbureau. The Standing Committee of the Political Bureau consists of seven people who wield the real power in China. The Three Gorge project has recently received the blessings of Li Xian-Nian, former president of China, and Hu Yao-Bang, former General Secretary of the Chinese Communist Party.

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        ┌─STATE─┐────────────>┌─THREE GORGE─┐
        │COUNCIL│             │LEADING GROUP│
 ┌─────────┐       \│/                \│/
 │POLITICAL│      ┌─STATE───┐      ┌─THREE GORGE┐
 │ BUREAU  │      │PLANNING │      │ PROJECT    │
                  │COMMISSION│     │DEVELOPMENT │  │
   \│/             └────────┘      │CORPORATION │  │
 ┌─CENTRAL─┐                                        │
 │COMMITTEE│                                        │
                                                    │
    \│/                    \│/            \│/
 ┌29 PROVINCIAL┐    ┌─MINISTRY OF──┐   ┌STATE SCIENCE┐
 │REVOLUTIONARY│    │WATER RESOURCES│<─────>│AND TECHNOLOGY│
 │ COMMITTEES  │    │ AND ELECTRIC │   │ COMMISSION  │
                    │    POWER     │
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The Chinese water resource planning hierarchy and its relationship to the Revolutionary Communist Party.

Figure 2. The Chinese water resource planning hierarchy and its
           relationship to the Revolutionary Communist Party.

The National People's Congress. The Standing Committee of the National Congress currently consists of about 150 elected members from all over China. Many of these people live in the lower Yangtze valley. The National Congress solicits information for and approves budgets, laws, and major economic planning documents (Howe, Christopher).

The State Council. The State Council, under the direction of the National Congress, is headed by Premier Shao Ziyang. Its membership includes the Premier, his twelve Vice-Premiers, and all 41 Ministry chiefs and Vice-Ministers. The Council oversees the activities of all Ministries, and implements Five-Year Plans and the national budget. The Council also directs the activities of the State Planning Commission and the Bank of China.

The State Planning Commission. The State Planning Commission allocates investments for all energy and water resource projects. The SPC also formulates quotas and targets for Five-Year Plans. This agency has the command authority to compel lower echelons (i.e., Provinces and counties) to cooperate on matters of interest to two or more of them, such as navigation and relocations (Moyes, 1987).

The State Science and Technology Commission. The SSTC, which answers to the State Council through the Three Gorge Leading Group, coordinates and directs all activities regarding Three Gorge Dam research activities. It cooperates with the Ministry of Water Resources and Electric Power (MWREP), which oversees all aspects of project planning, design, and construction.

Ministry of Water Resources and Electric Power. The MWREP is a melding of the former Ministries of Electric Power and Water Resources, whose members disagreed strongly on the question of whether or not Three Gorge Dam should be constructed (Lieberthal).

The members of the former Ministry of Electric Power are deeply involved in national power system planning, and hold the view that cheap power must be brought on-line for industry and other uses as quickly as possible. These power planners are therefore opposed to Three Gorge Dam because of its huge capital requirement, and even more so because first power would not come on-line until year eleven of project construction (Dong). Li Rui, the most outspoken critic of the Three Gorge project, was chief of the Ministry of Electric Power's General Bureau of Hydroelectric Construction until it was combined with the MWREP. At this time, he was given the post of Vice-Minister, which he held until he was purged in 1959, possible because of his "obstructionist" attitude regarding Three Gorge Dam.

The former Ministry of Water Resources consisted primary of national flood control planners, who assumed the opposite viewpoint and favored Three Gorge Dam as the most efficient way to contain the extremely damaging Yangtze River floods. Dong Xuecheng, chief of research and design at the YVPO, is typical of the highly-placed engineers who favor the high top-of-dam alternative because of its greater flood control capacity. Mr. Dong was born in Wuhan the year after the flood of 1931 destroyed the city and killed 145,000 people. His parents, who barely escaped with their lives, so impressed him with the magnitude of the suffering they had witnessed that he decided to

become a river control engineer. He is not alone in his opinion that a medium dam height (175 meters) is not capable of absorbing excess flow from an exceptionally large flood. A medium dam would only buy a few days of warning, and then, with its flood storage space filled, would pass the peak flow directly downstream without attenuation. This would be disastrous, since the construction of the dam would encourage accelerated development in the downstream floodplain.

Since 1975, the MWREP has been directed by Minister Madam Qian Zhengying, who visited Portland in November 1980. She has been a Party and cadre member since 1945, and is a graduate of the University of Shanghai. During the Cultural Revolution, she was lucky enough to escape banishment to the communes and was appointed Minister of Water Conservation. Her strong support of the Three Gorge project became evident when she ordered rebuttal articles written in engineering journals in response to a 1980 U.S. delegation's recommendation that a series of smaller dams be constructed instead of the single Three Gorge Dam (ENR, 1980 and 1984; Xianyi).

Yangtze Valley Planning Office. The YVPO, successor to the Yangtze Valley Planning Commission (YVPC) in 1956, is located in Wuhan. Its staff of 12,000, headed by Commissioner Wei Tingzheng, is responsible for all Three Gorge project planning and design. When the post-Cultural Revolution reconstruction on the Gezhouba project began in earnest, control of the YVPO passed from Premier Zhou Enlai to the Ministry of Water Resources and Electric Power.

Lin Yishan directed the YVPO until 1978. He was originally transferred from duty as a Fourth Field Army brigade commander to the

post of YVPC chief. Although Lin had no engineering experience, he relished the highly technical job of overseeing the preliminary design of the high dam and gradually came to see it as a distinguishing feature of the YVPC, and therefore, "his" project (Wang, Fuyuan). He defended the high dam vigorously in the face of well-organized opposition. In a very real sense, he championed the project and was its most ardent supporter. Much of the debate between pro- and anti-dam factions can be summarized by outlining the lengthy Lin Yishan/Li Rui debate.

Eventually Lin was replaced by Wei Tingzheng as director of the YVPO. Wei, a University of Shanghai graduate, has accumulated forty years of experience in water resource planning while rising through the ranks of the YVPC and the YVPO (Wei, 1985b).

Ministry of Communications. The Ministry of Communications (MOC) plans and directs all transportation and communication activities within the People's Republic of China. All Yangtze River navigation matters are addressed by its subordinate agencies, the Department of Navigation, the Three Gorge Navigation Office, the Navigation Leading Group for Three Gorges Engineering, and the Bureau of Yangtze River Navigation (Shi; Moyes, 1987). These agencies have expressed opposition or doubt regarding Three Gorge Dam because navigation will be disrupted during project construction, and due to perceived siltation problems in the upper reaches of the reservoir near Chongqing. If a high dam option is constructed, the river could drop its load of entrained silt directly in and around the Chongqing Harbor, and dredging costs would be extremely high. The MOC in particular has

pushed for expensive and elaborate temporary facilities in the form of locks and shiplifts in an attempt to drive the price of the project up as much as possible ("gold-plating"). The MOC has recently supported the 180-meter normal water surface elevation, possibly in the hope that excessive relocations costs will cause the project to be permanently shelved (Lieberthal).

Other Ministries. The Ministry of Machinery will fabricate most of the metal structures required at the Three Gorge project, to include the turbine-generator units (USBR, 1984). The Ministry of Foreign Economic Relations and Trade deals with foreign financing of projects built in China, and coordinates activities of the World Bank pertaining to the Three Gorge project. Several other Ministries play secondary roles in the planning and development of the Three Gorge Dam and Reservoir.

The China Three Gorge Project Development Corporation (CPDC). This agency's general mission, as directed by the Three Gorge Leading Group, is to oversee construction and operation of the Three Gorge project, and to help coordinate technical, financial, and physical foreign assistance. The CPDC is currently operating the Gezhouba project. Its main office was established in Yichang in late 1984, and it opened a branch office in Peking in 1985 (Moyes, 1986).

POSITIONS OF THE PROVINCES AND CITIES

General.

The costs and benefits of the Three Gorge Dam and Reservoir, whatever its configuration, will be distributed inequitably to upstream and downstream Provinces. Hubei and Hunan Provinces, immediately

downstream of the project, will receive the lion's share of flood control and hydropower benefits, while Sichuan Province will be short-changed in both areas, on top of being saddled with the burden of paying for the relocation of its residents.

A classic rivalry has developed between Chongqing and Wanxian. Whatever height of dam is finally selected, one city will win great navigation benefits, while the other will lose just as heavily. Near the river delta, Shanghai City will receive some navigation and water supply benefits due to increased low-flow releases from Three Gorge Dam, and northeastern Provinces may one day receive large irrigation benefits if a large-scale South to North water diversion scheme is implemented after Three Gorge construction.

Sichuan Province. Sichuan Province was pleased by the 1984 U.S. delegation's recommendation to construct a series of smaller dams because the Province, not the cities, would have to pay for any permanent relocations that would result from the construction of the reservoir. Additionally, Sichuan Province has been allocated only 1,000 megawatts of power from the project, regardless of its ultimate installed capacity. The reasons for this small allocation are not clear, but the Province's attitude is generally "the lower the dam, the less we suffer."

Sichuan objects to a high dam primarily because it will have to handle the logistics and costs for most of the permanent relocations caused by the reservoir. Recognizing this problem, the central government has recently proposed the creation and subsidizing of a 30th Province. This new geographical subdivision would be called Sanxia

(Three Gorge) Province, and would include parts or all of Wanxian, Yichang, Enshi, and Fuling Prefectures (Lampton).

Sichuan possesses one of the fastest-growing industrial sectors in China. Its resultant thirst for electrical power compels it to favor the construction of a series of "smaller" (500-1,000 megawatt) hydro stations on the Yangtze tributaries within or near its borders. If this option were selected, the Province would receive first power in about seven years, as opposed to eleven years for the Three Gorge project. And, of course, there would be no 1,000 megawatt limitation on installed capacity.

The Downstream Provinces. The Yangtze flows eastward below Gezhouba Dam through Hubei and Hunan provinces, which contain the most densely populated and fertile plain in China, known as the "country of rice and fish" (Cheng). Eighty percent of the cultivable land area in the Yangtze basin lies downstream of Gezhouba Dam. This area includes 126,000 square kilometers of rich alluvial plain, of which 50,400 square kilometers is currently under cultivation. More than 75 million people live in this plain (MWREP, 1983b).

The most immediate flood threat is to the critical Jinjiang Levee, whose main purpose is to protect Wuhan and 12,880 square kilometers of farmland (MWREP, 1983b). Chapter IV describes in more detail the benefits that these plains will reap from the construction of a single large dam. Put simply, a single high dam will be capable of containing much larger floods than a series of smaller dams, and so Hubei and Hunan Provinces favor the single-dam option.

Chongqing and Wanxian. A natural rivalry has emerged between Chongqing and Wanxian, the two major cities that will be most directly affected by the construction of any single Three Gorge Dam. As far as navigation and relocations are concerned, what benefits one will adversely affect the other. Therefore, the City of Chongqing favors a 180 meter normal water surface elevation, while Wanxian City is lobbying for a water surface elevation about thirty meters lower.

Chongqing is facing a classic tradeoff: at higher water elevations, it will reap larger navigation benefits, but will also pay a stiff price in terms of subergence of industrial and historic sections of the city.

Numerous members of the National Congress hail from Chongqing, and believe that the high dam may have been politically feasible two decades ago. However, the Cultural Revolution broke off studies in this area, and in the meantime the city nearly doubled its population. Much new industry was constructed in the area between elevations 160 and 200 meters, and low-dam proponents believe that China cannot efficiently achieve the Four Modernizations goal of advancing the industrial sector if it builds factories and then tears them down just a few years later (Huang).

It is also important to the highly-developed Chinese sense of history that Chongqing was the country's interim capitol during most of World War II. It would be unthinkable to many members of the National Congress to move large sections of the city that represents such sacrifice by the people.

The magnitude of Chongqing's historic and industrial assets from elevations of 160 to 180 meters is much less than from 180 to 200 meters. Therefore, it appears that losses incurred up to a normal water elevation of 180 meters would be acceptable, due to the large navigation benefits that would accrue at about 180 meters normal water surface elevation.

If Chongqing is willing to bear the cost, a high dam would remedy the terrible navigation conditions that now exist in the Gorges (these hazards are described in Appendix A). A normal water elevation of 180 meters would allow 10,000 tonne tows access to the city and would establish Chongqing as one of China's major ports.

However, the twenty-meter annual fluctuation of the reservoir for flood regulation could lead to extensive silting within the river channel from 32 kilometers upstream of the city to 70 kilometers below it (USBR, 1984). Sediment might also accumulate within the harbor itself. Proponents of the high dam assert that silt accumulation will only hinder navigation fchannel from 32 kilometers upstream of the city to 70 kilometers below it (USBR, 1984). Sediment might also accumulate within the harbor itself. Proponents of the high dam assert that silt accumulation will only hinder navigation for an average of ten days per year, and then only after seventy years of project operation.

The City of Wanxian is pressing for the construction of a dam with a normal water surface elevation of 150 meters. This elevation would create a lake with Wanxian at its head, and the city would attract river trade from those vessels not willing to tackle the remaining 250 kilometers of unimproved waterway to Chongqing (US3GWG). If Chongqing

is successful winning a 180 meter normal water surface elevation, most of Wanxian's trade district would be submerged, and the reservoir backwater resulting from a large (50+ year) flood would obliterate most of the remaining sections of the city.

THREE GORGE DAM: THE KEY QUESTIONS

Overview.

The two critical questions in the debate over Three Gorge Dam have been;

(1) Which alternative should be constructed: a single high dam or a "cascade" of smaller projects on the Yangtze main stem and its tributaries?

(2) If the Three Gorge Dam is built, how high should it be, and what should be the range of the normal reservoir water surface elevation?

The first question, debated for years, has essentially been settled. It is generally agreed that China now has the technological capability to construct the Three Gorge project at some time in the near future. The only remaining serious point of contention is the allowable normal water surface elevation range of the project's reservoir.

The discussion between high dam proponents and cascade development supporters is neatly summarized in the views of a group of high-ranking United States engineers that visited China in 1980, and the subsequent reply of several high-ranking Chinese engineers. This debate over water surface elevation range is quite complex, and the 'players' are likely to be arguing long after the dam is built and the reservoir is filled.

The Paramount Question: Single or Multiple Dams?

Background. Should China sink a huge amount of capital into a gigantic dam at the outlet of the Three Gorges, or should it develop the Yangtze River as a system over time with a series of smaller projects on the main stem and tributaries? The arguments set forth by the visiting United States delegation and the responses by Chinese water resource planners serve to outline the advantages and disadvantages of both alternatives.

In March of 1980, a group of 24 U.S. engineers, including officials from the Bureau of Reclamation (USBR), Corps of Engineers, Tennessee Valley Authority (TVA), Department of Energy (DOE), and the Bonneville Power Administration (BPA), visited China and reviewed the project plans as they stood at that time. The proposal called for a 215-meter high dam, 25,000 megawatts of installed capacity, and world record-sized six-step navigation locks (Wei, 1985a).

Upon the completion of their visit, the U.S. delegation announced that they had persuaded the Chinese to drop plans for a single dam in favor of a series of four to six smaller dams on the Yangtze main stem (ENR, 1980). The Chinese (in particular Minister Madam Qian of the MWREP) were surprised and angered by this premature statement, and published vigorous rebuttals in several international engineering magazines and journals. The most notable of these was a five-page article in Engineering News Record authored by the YVPO Commissioner, Wei Tingzheng, and two other prominent engineers. The point-by-point recommendations of the United States delegation and the subsequent Chinese replies are summarized in the following paragraphs.

Construction Site. The United States delegation pointed out that the proposed project is only 40 kilometers upstream of the existing Gezhouba Dam. This means that 100 kilometers of usable slackwater navigation channel and about 15 meters of generating head will be 'wasted' if Three Gorge Dam should be constructed at the Sandouping site. They asserted that the project should be located further upstream, or, better yet, a series of smaller dams should be constructed on the Yangtze main stem and tributaries.

The Chinese contingent replied that the Sandouping site is located in the Xiling Gorge, which provides by far the best granitic foundation in the area. This site is not as cramped as the others that were examined by experienced geologists. Furthermore, the presence of Sandouping Island in the middle of the river would ease construction considerably, since a diversion channel would not have to be built.

For smaller alternative projects, the diversion of the Yangtze's huge flow and the construction of cofferdams for each project would be extremely difficult, dangerous, and expensive. Cofferdam construction would only have to be carried out once with the large project.

Navigation. It was the opinion of the United States contingent that the three-stage double-lock system proposed at the Three Gorge Dam would allow a maximum of only nine lock cycles per day. All vessels would have to be lifted through the entire height of the dam, even though their destinations might be only a short distance upstream. Therefore, a series of smaller dams should be built on the Yangtze main stem.

The Chinese replied that, due to the rugged topography of the area, there is very little industry between the Three Gorge Dam and Chongqing, which would be at or near the upper end of the lake created by the dam. In any case, most river traffic above Gezhouba Dam would be destined for Chongqing if the large dam is built, or both Chongqing and Wanxian if the smaller dam is constructed.

A single high dam would benefit downstream navigation as well. Many shoals in the lower reaches of the Yangtze hinder waterborne access to such critical facilities as the huge Baoshan steel works, and dredging must be carried out continuously. A series of small dams above the Gezhouba project would not have enough active storage to guarantee the continuous minimum flow of 8,500 cubic meters per second (CMS) required to cover these shoals, and expensive dredging would have to continue.

Sedimentation. The United States delegation asserted that the Yangtze would slow and drop most of its 2.5 billion ton annual sediment load behind the Three Gorge Dam. This sediment would hinder navigation near Chongqing and might cause estuary scour damage at Shanghai that is similar to that suffered by the Nile estuary after the High Aswan Dam was built.

The Chinese replied that they had provided 32 sediment tubes to pass silt at the Gezhouba project, and would also include bypass facilities at the Three Gorge Dam that would pass 75% of all entrained sediment. The Chinese scientists calculated that, even after 70 years of sediment accumulation at Chongqing, navigation would be hindered by shoals only an average of 10 days each year. In addition, partial

sediment entrapment and the elimination of low flows by the Three Gorge Dam would relieve them of the immense and costly burden of continually raising about 30,000 linear kilometers of downstream flood control levees.

Security Considerations. The United States group asserted that the Chinese, by putting all of their eggs into one basket, would create an insurmountable security problem. One medium-yield cruise missile could obliterate the Three Gorge Dam, unleashing thirty cubic kilometers of water that would kill tens of millions of people and destroy much of China's heavy industry. As background, the contingent cited an instance where the Royal Air Force used water-skipping bombs during World War II to destroy three German dams, releasing floodwaters which subsequently leveled much of the industrialized Ruhr Valley. Once again, the U.S. engineers urged the Yangtze Valley Planning Office to build a series of from four to six smaller reservoirs on the main stem.

The Chinese engineers replied that their economy would be needlessly hampered if the government simply stopped constructing major projects because they might pose a hazard in future times of war. In any case, their preliminary dambreak studies showed that, if the 175-meter dam were breached while its reservoir was at a level of 150 meters, about 19.7 cubic kilometers of water would be released. Using the limited pondage capacity of Gezhouba Dam, the peak flood flow could be reduced to a non-damaging level (about 56,700 cubic meters per second) before it arrived about eleven hours later at the Jinjiang Levee (MWREP, 1983b; Dong).

Summary of the Chinese Reply. The Chinese, in a series of articles published in several United States engineering publications, summarized their preference for a high dam by framing their reply in terms of the high dam's efficiency in meeting such needs as flood control, hydropower, irrigation, and food production.

The number one priority assigned to the Three Gorge project is not hydropower, but flood control. Even the most optimum series of smaller reservoirs would have only half of the flood control storage space of the single dam and would cost much more.

A series of smaller reservoirs would only generate about one-third of the energy annually that the large dam would. This would only improve power supplies locally, not nationally as required by the Four Modernizations.

One of the primary purposes of Three Gorge Dam would be to increase national agricultural efficiency. A large single dam would supplement seasonal low flows sufficiently to allow the construction of a major South-North water diversion project near Shanghai. Additionally, the construction of several smaller reservoirs would inundate much more farmland than a single large project, and China cannot afford to lose more than the absolute minimum possible amount of arable land.

A HISTORY OF THE DEBATE OVER THREE GORGE TOP-OF-DAM HEIGHT

Introduction.

The benefits and costs of the Three Gorge High Dam are unevenly distributed among a large number of provinces, counties, and cities. All of these entities, in addition to powerful personalities and

government agencies on every level, are involved in the planning and decisionmaking process. It is impossible to describe in detail the almost infinite number of interactions that have led to the shaping of policy regarding the Three Gorge Dam. However, some of the more important events are summarized below.

This section explores the evolution of economic and water resource policy and planning that has caused the acceptable upper and lower limits of the Three Gorge top-of-dam height to narrow steadily.

The Original Project Configurations.

Dr. Sun Yet-Sun, in his book Plan for Industrialization of China and during his 1923 lecture, "Principle of People's Livelihood," envisioned a Three Gorge project dedicated primarily to producing more food for the masses. He calculated that the powerhouses would produce work equivalent to 2,400 million peasants, and would irrigate more than four million hectares of land (Savage).

In 1930, the Chinese government held its first talks with experts from the United States Bureau of Reclamation (USBR) to discuss the feasibility of a dam in the Three Gorges. Shortly following this discussion, the Sino-Japanese War (1937-1945) and a long period of civil war (to 1949) disrupted nearly all planning and interaction with foreign water resource experts.

Serious United States involvement in the planning of the project began in 1943, when Dr. John L. Savage, the Bureau of Reclamation's Chief Design Engineer, visited China for an extended period of time as a consultant to the Yangtze River Water Conservancy Commission (later the YVPO). He later published his "Preliminary Report on Yangtze Gorge

Project," which set forth five alternative plans for a 225 meter dam, ranging in cost from 950 to 1,030 million dollars, at 1946 price levels.

Reflecting the nation's priorities at that time, the project's primary purpose would be to increase food production. The reservoir would include 27.1 cubic kilometers of flood control storage, sufficient to contain the flood of record at that time (the 1870 flood). The project would also divert more than a fourth of the river flow (5,800 CMS) during the growing season of April through October in order to irrigate two crops of rice per year on 4.05 million hectares of land (Savage).

Forty-eight power tunnels would convey water to one hundred turbine-generator sets housed in 'bombproof' underground powerhouses. The total installed capacity of these units would be 10,560 megawatts, of which 6,000 megawatts would be firm. Five thousand megawatts of power would be dedicated to producing fertilizer. The average annual energy production of these alternative projects was estimated to be 81.7 terawatt-hours (Savage).

These plans were consigned to the files when a long period of internal strife broke out in China.

New China's Turbulent Early Years.

China's long civil war exhausted many of its basic resources. At the end of the conflict, Russia stripped Manchuria of about 1,000 megawatts of electrical generating equipment, reducing the total installed capacity of the Chinese national power system to only 1,850 megawatts in 1949.

In 1949, Mao Zedong inaugurated the People's Republic of China (New China). Three years later, Premier Zhou En-Lai announced the First Five-year Plan, which was launched in January of 1953.

The enormous 1954 flood forcibly brought home the need for flood control in the lower Yangtze basin. Late that year, Lin Yishan, director of the Yangtze Valley Planning Commission, met with Mao and Zhou to urge immediate detailed planning for a large Three Gorge flood control project. Zhou, who had direct operational control over the YVPC, was therefore directly responsible for Three Gorge planning (Lieberthal).

The Chinese examined two areas. Fifteen possible damsites were inspected in the 25-kilometer long Meirentuo Region, which stretches from Meirentuo to Nantuo, and the 13-kilometer long Nanjingguan reach from Shipai to Nanjingguan. Eventually, studies were narrowed to the 45-kilometer long Xiling Gorge. Finally, in 1979, the State Council accepted the MWREP's recommendation of the Sandouping damsite (C3GPDC).

The Lin-Li Debate. In 1954, the lengthy debate between Lin Yishan and Li Rui, director of the Ministry of Electric Power's General Bureau of Hydroelectric Construction, first erupted. Lin pushed for immediate planning and construction of a high dam, while Li asserted that such a project was far beyond the the nation's capabilities. He urged construction of smaller upstream dams and downstream flood control works first, to be followed by the building of a lower Three Gorge Dam at some time in the future when the economy could support it.

In 1958, Lin and Li formally debated the merits and drawbacks of a single high dam before Chairman Mao, who had taken a continued interest

in the project. Lin stressed that Three Gorge Dam was the only rational solution to the Yangtze River problems and that construction should begin immediately on a 200+ meter dam for navigation, hydropower, irrigation and especially flood control benefits. Li countered by saying that the dam was technically still out of reach and that China could not fully use its vast hydropower output. Mao decided in favor of Li, but supported continued planning (Lieberthal).

The First Push for Construction. Early studies had considered normal reservoir pool elevations ranging from 190 to 260 meters. Opponents of the high dam had already stressed the excessive costs of relocations for the higher pool elevations. Therefore, at the 1958 Chengdu meeting of the Communist Party's Central Committee, the range of acceptable alternatives was narrowed to those with normal pool elevations ranging from 190 to 205 meters.

The Chengdu and Wuhan conferences directed Lin Yishan to begin preliminary project planning. The emphasis of these studies was upon resolving the many unanswered technical questions posed by Li Rui and his allies. For the next two years, more than 10,000 technical personnel labored on this effort. The result was the "Construction Proposal and Preparatory Construction Plan for the Three Gorge Water Resources Project", whose purpose was to attempt to push Three Gorge into the construction stage by having it included in the next Five-Year Plan. The proposed 200-meter dam would include an installed hydropower capacity of 13,400 megawatts (Lieberthal).

By 1955, the infrastructure essential to the functioning of the Chinese postwar economy had been largely reconstructed. Mao ordered a

widespread reforestation program and the nationalization of foreign-owned industry. The USSR assisted in the launching of a program of large hydropower project construction, and offered technical help to a 1,000 man Yangtze survey team from 1955 to 1957 (Lieberthal).

Political Turmoil Stalls the Project.

Beginning in 1957, any momentum gained in pushing the project towards construction was overwhelmed by events on a national scale. In May, the "Hundred Flowers" campaign encouraged the free exchange of ideas in a public forum. Apparently, the result appeared more like weeds to the Chinese leadership, which launched a "rectification" campaign to supress dissent after only three weeks. This campaign used intellectuals as scapegoats for the country's woes (Howe, Christopher).

The Great Leap Forward began in 1958. Collectivization and rural self-sufficiency became the favored tools of economic advancement, and to this end, eighty thousand small hydropower plants were built in the following decade (Deng). A vast amount of pressure from both above and below caused the pace of construction to proceed at a frenetic pace during the Great Leap, sometimes to the detriment of quality. The central government perceived an envy of more developed countries among the masses, and anything "big and foreign" became mistrusted.

Two years after it began, the Great Leap collapsed due to administrative confusion, resource misallocation, and a lack of unified middle-level leadership. The Soviets abruptly withdrew their technical assistance at about the same time, and the construction of many large power projects ground to a halt in the midst of widespread confusion. China's annual energy production declined 34 percent in a single year

(Beijing). The overall result was disastrous to China's economy, and the ambitious plans for Three Gorge Dam were buried in the panic.

The two years from mid-1960 to mid-1962 are sometimes referred to as "the Chinese Great Depression" (Howe, Christopher). The agricultural sector was in chaos, many factories were closed, and there were even reports of starvation in isolated rural areas.

Finally, in December of 1964, Premier Zhou reported that the worst of the depression was over and announced the "Four Modernizations" - defense, technology, industry, and agriculture. He also acknowledged that foreign technology could assist the Chinese drive towards full development (Howe, Christopher).

The Cultural Revolution.

General. Attempts to include Three Gorge in the Third Five-Year Plan were derailed by the Cultural Revolution, which crippled China's engineering community, and by a conservative mood brought on by previous design and construction errors at other large dams. Immediately following the Cultural Revolution, a Sino-Soviet war scare caused the project to be shelved in deference to security concerns.

The Intellectual Community is Disabled. The Great Proletariat Cultural Revolution was launched in 1966. The government abolished examinations and shut down universities and schools. Most scientists and engineers were 'sent down to the countryside' or remained closely monitored and restricted in their research activities, and the promising economic recovery stalled.

The Cultural Revolution disabled the intellectual 'community' and its potential in China. Three Gorge Dam opponents noted this as they

became more vocal than ever in their views that the country simply did not have the technical knowhow to construct a project that was at the world state-of-the-art in almost every respect.

Dam opponents emphasized in particular that the favored Three Gorge Dam alternative at the time included 25,000 megawatts of installed capacity, which would require the installation of 1,000 megawatt turbine-generator sets. Even today, these are nearly fifty percent larger than the current 700 megawatt world record holders at Itaipu and the Grand Coulee Third Powerhouse. The government, in keeping with its policy that the project would be an "all-China" effort, was keenly aware of the fact that the limit of Chinese turbine fabrication capability was only about 200 megawatts in the early 1970's (Smil, 1978).

China still suffers from the long-range effects of the Cultural Revolution, and lags behind the most advanced countries in some areas of technology and management. However, the country's top leadership remains determined to learn from the rest of the world through an aggressive program of international technology transfers.

The War Scare. Security fears were resurrected when tensions flared between the Chinese and the Soviets in 1969. Chairman Mao stated that preparations for impending war took precedence over the construction of large civil projects such as Three Gorge Dam (Lieberthal). Premier Zhou echoed these security concerns. Three Gorge Dam could not advance in the planning process against the wishes of these two men.

Previous Mistakes. The conservative mood regarding very large construction projects, including Three Gorge Dam, was heightened by the planning and construction mistakes made by the Chinese at "showcase" projects such as Sanmenxia and Gezhouba Dams. These were a source of embarrassment, and the Chinese could not afford additional errors when dealing with the "cornerstone" of the Four Modernizations, the Three Gorge Dam.

Planners had anticipated 2,000 megawatts of installed hydropower capacity at the Sanmenxia Dam and Reservoir on the Yellow River. Though they knew that this river has an extraordinarily large sediment load, they underestimated it badly. Some major floods consist of 'waters' that are more than seventy percent silt by weight, and the reservoir silted-in almost solidly in just two years. The installed capacity of the powerplant was reduced to only 250 megawatts.

Further South, the People's Liberation Army was in charge of Gezhouba construction for three years, because almost all experienced construction managers had been sent down to the countryside during the Cultural Revolution. When these managers returned in 1972, they found that the concrete work at Gezhouba was substandard, and a year was wasted in tearing out half a million cubic meters of existing concrete so that construction could restart (ENR, 1984).

The Age of Pragmatism Begins.

General. After the deaths of Mao and Zhou and the criticism of the "Gang of Four" in 1976, the spread of pragmatism began. "Walking on two legs" (a balance of old and new technologies) became a new national policy. Material incentives were offered to boost production

and advance education, and Hua Guofeng promised that the "hundred flowers would bloom again" (Howe, Christopher).

Attention Returns to the Three Gorges. In 1977, Gezhouba Dam construction was well under way. Since this project was designed to act as the Three Gorge flow reregulator, attention was naturally directed back to the Three Gorge project, which had gained national recognition as one of the cornerstones of the "Four Modernizations." Vice Premier Deng Xiaoping and Communist Party chairman Hu Yao-Bang gave priority to the construction of the project.

The Ten-Year Plan. Following more than two decades of internal upheaval that virtually precluded interactions with the West, a renewed era of cooperation was opened in 1978 when the Department of Energy's Secretary James Schlesinger proposed joint U.S./Chinese efforts in five areas of energy development, including hydropower. Also in 1978, Hua Guofeng announced the Ten-Year Plan for 1976 to 1985, which originally included provisions for the construction of Three Gorge Dam.

In 1979, the Ten-Year Plan was scrapped, and with it plans to construct Three Gorge Dam in the near future. In keeping with a continuing conservative mood, construction instead was approved for four large hydropower stations on major Yangtze tributaries. These plants - Wujiang, Ankang, Dongjiang, and Wan'an - are now complete, and possess a total installed hydropower generating capacity of 2,430 megawatts (Chen).

Li Rui Returns. The high-dam/low-dam debate was returned to the front burner once again when Li Rui returned to the stage after twenty years in disgrace. Li and Lin Yishan immediately picked up the cudgels

regarding Three Gorge Dam again. The arguments set forth by both were nearly identical to those they had advanced two decades earlier. Lin pushed for immediate construction of a high dam and Li wrote rebuttals to the State Council and others reiterating his earlier arguments, in particular concerns about China's capacity to construct a project of such magnitude.

U.S./China Cultural Exchange Begins. In September of 1979, Deng Xiaoping visited Washington to open a new era of cultural exchange. Deng and Vice President Walter Mondale signed a five-year technological assistance agreement entitled 'Protocol on Cooperation in Hydroelectric Power and Related Water Resources Management.' This agreement outlined cooperation in technology exchange, including cross-training of Chinese engineers with the Corps of Engineers, Bonneville Power Administration, and the Tennessee Valley Authority. It also provided for separately-negotiated technical cooperation on several specific projects, including Three Gorge Dam.

Meaanwhile, participants in the April 1979 State Council meeting witnessed dam proponents once again attempting to attach the Three Gorge project to the current (Sixth) Five-Year Plan. Two months later, opponents had their turn at bat at the Second Wuhan Conference, where they pointed out, once again, China's technical and manufacturing limitations, with particular attention to turbine-generator and lock gate manufacture (Lieberthal). At this time, the State Science and Technology Commission recognized that the shortage of power was throttling the Chinese economy, and began a detailed evaluation of the country's energy resources and loads. When the Sixth FYP was submitted

for approval, the role that Three Gorge would play in national energy development was still uncertain, so the project was not included in the Plan.

Developments Since 1980.

International Cooperation. The disagreements between the United States and China regarding the Three Gorge Dam and Reservoir have been previously described in this section. During the last several years, the fundamental differences in philosophy between the two countries have been largely resolved through a spirit of cooperation and teamwork, but the debate among Chinese agencies remains as heated as ever. In the process, the Chinese government has made it quite clear that it will maintain control over the construction of the project, although it will certainly welcome foreign technical assistance. The United States has accepted this attitude. In the past five years, the two countries have exchanged more than thirty energy- and technology-related delegations of scientists and engineers, and about fifty Chinese engineers have trained in the United States for periods ranging from three to fifteen months. More than one hundred privately-owned engineering and consulting firms from a dozen countries have contacted the Chinese government independently in order to express an interest in providing technical services (Harza).

The Feasibility Study Configuration. The MWREP's basic twelve-volume Feasibility Study, completed in 1983, recommended a normal water surface elevation of 150 meters and a top-of-dam elevation of 165 meters. This plan would require 330,000 permanent relocations below the maximum reservoir water level required to contain the 20-year flood

level. However, this dam height would provide only 20-year flood protection in downstream areas without using the Jinjiang flood detention area.

In April of 1984, after the National Planning Committee had reviewed the Feasibility Study, the State Council approved the single 165-meter Three Gorge Dam (C3GPDC). This was a critical step for the Three Gorge project; basic planning was finally considered complete and the State Council formally included it in the Seventh Five-Year Plan (1986-1990). The State Council also ordered the YVPO to perform a preliminary design report (named the Comprehensive Report) and an environmental impact statement, scheduled for completion by the end of 1984.

Until about 1980, a dam height of 190-200 meters had been favored. It is possible that the State Council opted for the lower dam in order to allay some of the primary concerns of the dam's opposition, the most telling of which was relocations costs. Figure 3 shows that permanent relocations and the amount of precious farmland inundated increases sharply with a higher normal reservoir water surface elevation, particularly above an elevation of 180 meters.

Vice Premier Li Peng was placed in charge of the new China Three Gorge Project Development Corporation, whose purpose would be to act as a clearinghouse for all Three Gorge coordination during design and construction, and which would thereafter operate and maintain the Three Gorge and Gezhouba projects (Moyes, 1986). This Corporation, established in December of 1984, now has offices in Yichang and Beijing (C3GPDC).
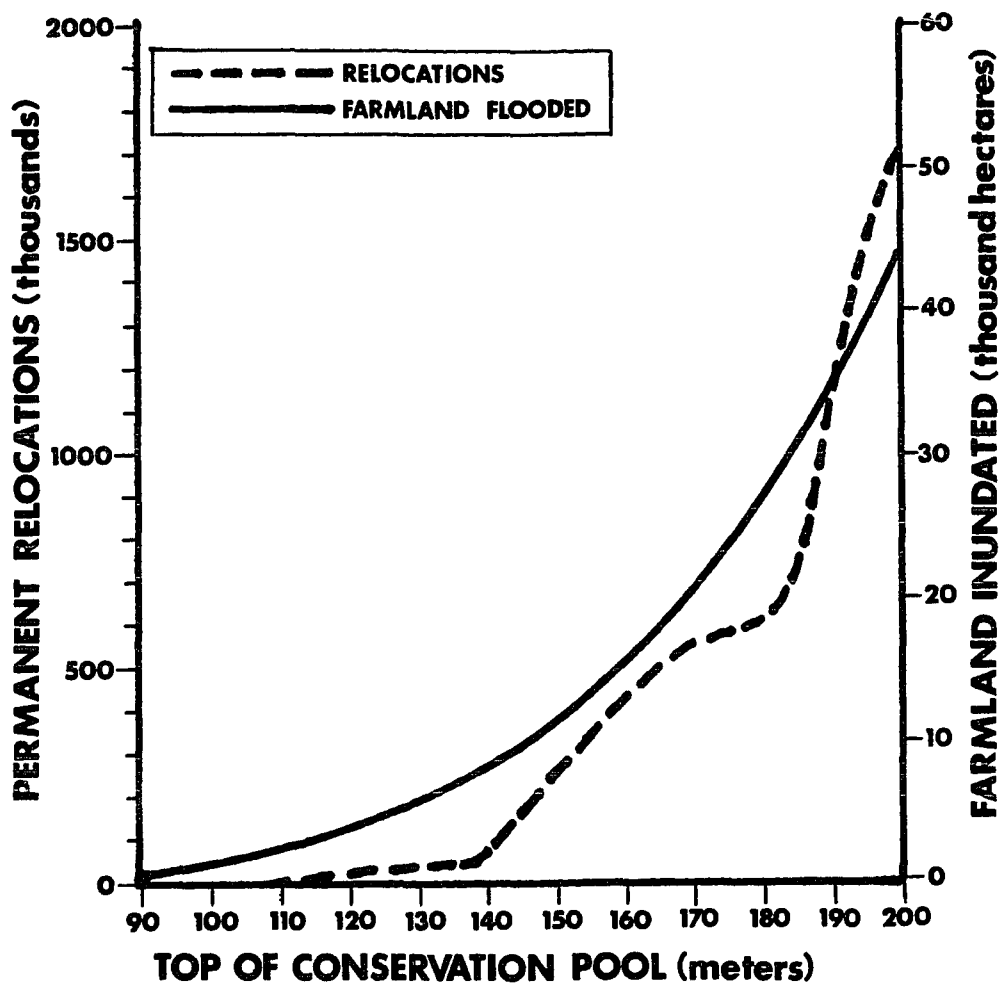
Figure 3. Effect of alternative Three Gorge Reservoir normal water surface elevations on permanent relocations and farmland inundation (Clowes, 1987c).

In order to leave the option of an early construction date open, and to reduce huge interest costs during project construction, site preparation at Sandouping Island began in 1984. However, once again, matters on a national scale interfered with project construction startup. Rapid economic growth in 1984 led to a $13 billion foreign

trade deficit. Extensive contrade deficit. Extensive construction had also resulted in a shortage of capital for the construction of large projects. The Three Gorge Dam was dropped from the Seventh Five-Year Plan early in 1986, which means that construction can now begin no earlier than 1988 (Lieberthal). September's final review meeting was cancelled, following a year of aggressive technical and economic objections to the Three Gorge project.

Most major features of the Gezhouba project were completed by 1984, and a large percentage of the work force became available to begin site preparation work on Sandouping Island.

On August 3, 1984, the US Bureau of Reclamation and the China National Technical Import Corporation signed a five-year consulting agreement. This document recognizes that China alone is responsible for the construction of this project, and the USBR, with assistance from the Corps of Engineers and other government and private consultants, would provide whatever technical assistance the Chinese government desires (Wei, 1985a).

However, the United States government, in an attempt to save six million dollars of nonreimbursable consulting fees, missed a golden opportunity to be a part of the planning of this historic project.

In 1984, Vice-President Bush had personally volunteered U.S. resources to perform the Three Gorge detailed feasibility study, but Congress failed to appropriate the required funds in 1985. The Canadian government did not pass up the opportunity for a potentially huge return in consulting fees for a relatively small investment. They created an agency referred to as the Canadian International Project

Managers Yangtze Joint Venture (CIPM), funded by the Canadian International Development Agency (CIDA), and checked by the World Bank (Moyes, 1987). Canada, because of its willingness to take a relatively small risk and do some free consulting work, is now taking advantage of previous United States research and is deeply involved in the planning of Three Gorge Dam and Reservoir.

The only U.S. agency still directly involved in project planning is the Bureau of Reclamation, which possesses a five-year, two million dollar, 100% reimburseable agreement for various small studies, renewable until 1988 (Moyes, 1986).

The State Council Raises the Top of Dam. The Preliminary Design Report, completed and submitted to the State Council in 1984, recommended raising the top-of-dam height to 175 meters in order to obtain additional flood storage space. The Report kept the normal water elevation at 150 meters in order to hold down the huge costs of permanent relocations (C3GPDC). The State Council approved this plan in March of 1985, but with reservations.

The reasoning behind this move was straightforward. If the 1954 flood occurred today in the absence of a Three Gorge project, the full array of Jinjiang flood detention areas would be used to store excess water. Such an event would inundate between 650,000 and 1.3 million hectares of agricultural lands and would require the temporary relocation of from three to six million people. Property damage alone for each 'full' use of the flood diversion areas would be staggering in terms of damage inflicted upon the poor peasantry; the cost, primarily in lost crops, would range from $17 billion to $25 billion (Xianyi).

Raising the dam height from 165 to 175 meters would yield an additional 9.4 cubic kilometers of flood storage space. This additional storage would enable the Jinjiang levees to withstand the 100-year flood without using the Jinjiang floodwater impoundment areas, and the 1,000 year flood could be passed while using the impoundment areas to their design limit.

This higher maximum flood control elevation would result in an additional 60,000 temporary upstream relocations and 4,660 upstream hectares of farmland being temporarily inundated during the 20-year flood (USBR, 1984). Therefore, over the expected 100-year project life, raising the dam height from 165 meters to 175 meters would "save" a vast amount of money and human misery even if the project would prevent the use of the flood detention areas only once in its century-long lifetime, an event that is almost certain to occur.

The 1985 Comprehensive Report. The revised 1985 Comprehensive Report included a comparison of the impacts of projects with maximum normal water surface elevations of 150, 160, 165, 170, 175, and 180 meters. A subsequent summary report entitled "Implementary Report of the Normal Pool Level for the Three Gorge Project in 1985" recommended a top-of-dam height of 175 meters. This report also recommended a normal seasonal rule curve fluctuation of from 140 to 170 meters, in order to obtain seasonal navigation benefits all the way to Chongqing (C3GPDC; Moyes, 1986).

The Current MWREP Plan. In September of 1985, the MWREP met to discuss the summary report mentioned above. As a result of this conference, the Ministry accepted the report's recommendation of a 175

meter top of dam height and a normal water surface elevation of 160 meters, which would require 422,000 permanent relocations. This action narrowed the field of alternatives under study to a normal pool elevation of either 160 or 170 meters. Also in 1986, the Ministry of Communications emerged in favor of a normal water elevation at 180 meters, joining Chongqing, which in 1983 had announced its support for this pool level in order to further its goal of becoming an important Yangtze River port. Sichuan Province continued to resist any plan with a normal water surface elevation exceeding 150 meters, due to the difficulty in dealing with refugees from the reservoir area.

The Current Situation. The Chinese economy has been enjoying a modest upturn lately, and the proponents of the project have recently been lobbying with renewed vigor. Infrastructure and support facilities for the project are nearly complete, including an access highway, 44 kilometers of 500-kilovolt transmission line connected to the national grid, site water supply, geologic preparation and site leveling, and three truck ferries (Harza).

Additionally, it appears that the industrial sector of Eastern and Central China is now capable of absorbing the energy generated by the Three Gorge powerhouses, if the first units come on-line at about the turn of the century (MWREP, 1983a). This removes one of the major stumbling blocks in the drive to get Three Gorge accepted and constructed. Until now, it has not been certain that industries in the project's service area could actually absorb its energy output.

Summary.

Three Gorge has naturally been pushed to the forefront by its

proponents whenever debate began as to which projects to place into successive Five-Year Plans. But, each time, events on a national scale overwhelmed efforts to nail down a firm start date for construction and the funds required to support it. In 1960, economic disorganization and the depression which followed the Great Leap Forward made financing impossible. Five years later, the Cultural Revolution caused severe stress at the highest levels of planning. In 1969, the Sino-Soviet war scare compelled Chairman Mao to shelve the project due to security considerations. Since that time, continued economic fluctuations and uncertainty about the ability of the economy to support the project and then to consume its outputs have kept it on the "back burner."

However, the future looks bright for Three Gorge Dam. Most technical objections have been overcome. China has advanced technologically and economically to the point that it is capable of tackling the construction of the world's largest flood control and hydropower station. Additionally, Eastern and Central China are now able to use the power that the project can provide.

Finally, the completion of Gezhouba Dam has naturally turned national attention towards the Sandouping site, just forty short kilometers upstream.

THE NEED FOR FLOOD PROTECTION IN THE LOWER YANGTZE PLAINS

The Fertile Yangtze Floodplain.

The Yangtze River drains nearly two million square kilometers of central and eastern China. Due to a relatively mild climate, rich soil, and easy river access, the middle and lower reaches of the river support China's highest concentration of agriculture, industry, and

population. Appendix A describes in greater detail the courses of the Yangtze and its major tributaries and the basin's current level of industrial and water resource development.

The area that will primarily benefit from Three Gorge Dam flood control operations is the Jinjiang Plain, which is located immediately downstream from the Gezhouba multiple-purpose project at Yichang. This extremely vulnerable low-lying area includes 1.5 million hectares of cultivated land and is home to 13 million inhabitants. This area has been consistently flooded, with resulting great damage and loss of life, for more than two thousand years.

In the general area of the Three Gorges, Yangtze River flood and discharge records of varying types and accuracies have been kept continuously for more than 2,100 years. During this extraordinarily long period of record, there have been 215 major floods on the Yangtze. Since 1153, there have been eight floods with a peak flow of 80,000 cubic meters per second (CMS) or more, including five with maximum flows exceeding 90,000 CMS. In the last century, the flow of the Yangtze has exceeded 60,000 CMS 21 times at Yichang. Detailed descriptions of the effects of large floods since about 1850 are available (Rodier).

Individual Large Flood Events.

Introduction. Table VII shows the historical death tolls, temporary relocations, and inundated farmland caused by relatively recent major flood events on the middle and lower reaches of the Yangtze River (MWREP, 1983b; USBR, 1985a). On the average, Yangtze floods kill five thousand persons and cause approximately one billion

TABLE VII

HISTORICAL DEATH TOLLS, TEMPORARY RELOCATIONS, AND INUNDATED FARMLAND
DURING MAJOR FLOODS ON THE MIDDLE AND LOWER YANGTZE RIVER FLOODPLAINS

(adjusted for current levee system conditions)

Year of Flood	Fatalities	Temporary Relocations	Farmland Flooded (hectares)
1931	145,500	285,500	3,067,000
1935	142,000	100,300	1,269,800
1949	16,700	150,000	1,820,000
1954	33,000	188,800	3,000,000
120-YEAR AVERAGES	5,000	11,500	100,000

References: MWREP, 1983b; ENR, 1984; Dong.

dollars of damage annually under current flood control system conditions. Of course, the large majority of these damages take place during very large floods, and most of the direct and indirect damages are attributed to lost crops.

The following paragraphs describe in detail the great damage caused by large Yangtze floods with relatively long return periods.

Nineteenth Century Floods. The 1860 Flood peaked at 92,500 cubic meters per second and broke the South Levee at Ouchi. Dongting Lake, a heavily-cultivated area that drains five major rivers, was completely inundated (MWREP, 1983b). This flood was approximately a 200-year event.

Just ten years later, the Yangtze produced the second largest flood of record, considered to be at least a 500-year event. The 1870 Flood followed a continuous general week-long downpour over much of the

Yangtze basin and produced the highest peak flow of record at 110,000 cubic meters per second (3,884,000 cubic feet per second) at Yichang. The irresistable force of millions of tons of water traveling at speeds of up to fifteen knots broke the South Songzi Levee and flooded Dongting Lake, and also burst the North Levee below Janli and flooded the northern areas of Jingjiang. The city of Fengdu, with a population of 35,000, was obliterated.

If a flood of this magnitude occurred at night without warning under current conditions, it is estimated that one million persons would drown. Most likely, 500,000 to 600,000 persons would drown if the flood occurred during the day (MWREP, 1983b; USBR, 1985; EW, 1985).

The 1931 Flood. In 1931, the deadliest Yangtze flood of all time killed 145,000 people and destroyed crops that would have fed 30 million persons for three months. Floodwaters covered more than 100,000 square kilometers of land, causing an estimated $13.5 billion of direct damages (1931 prices). Sickness and plague followed the recession of the floodwaters. Wuhan and Hankou Cities were flooded for three months (MWREP, 1983b). During the same year, the worst flood disaster in world history killed more than three million people on the Yellow River. Just four years later, the Yangtze killed 142,000 persons during the 1935 Flood.

The 1954 Flood. The 1954 flood inundated 123 counties and cities and represented the last time the Jingjiang flood retention area was used to protect the Jingjiang Levees. This flood killed 33,000 people and inundated more than three million hectares of farmland, despite the construction of 3,000 kilometers of major levees up to 16 meters high

and 30,000 kilometers of secondary levees since the 1870 flood. The trunk Chingkwong (Beijing-Guangzhou) railroad was out of operation for 100 days. Direct damages alone were estimated to be as high as $175 billion (MWREP, 1983b). This event showed that no system of levees, regardless of how extensive, can guard against all major floods on a river the size of the Yangtze.

If this flood occured today, the Jinjiang Levee would be breached, 13,000 square kilometers would be flooded, and it is estimated that five million would be driven from their homes. The Yangtze River would probably seek a new channel, with catastrophic consequences (MWREP, 1983b). The flood would require the diversion or storage of seventy cubic kilometers of flood water, and 785,000 hectares of farmland would be inundated. The flood would cause about ten billion dollars of direct damages alone to the rural sector and one to two billion dollars of expenditures in flood fighting, industrial production losses, and damages to cities and industry, thereby exceeding the entire cost of the proposed Three Gorge Dam (USBR, 1985).

Existing Flood Control Measures and the Channel Aggradation Problem.

Because a serious flood has occurred in the middle and lower Yangtze plains on the average of once every decade, the Chinese have constructed the world's largest system of dikes for protection, consisting of about 32,000 linear kilometers of embankment (Xianyi). These levees have a total fill mass of about thirty billion tons. To lend some idea of the immense size of these works, they have a volume which is about five times greater than that of the famed Great Wall of China.

Since the Yangtze river slows and meanders in its middle and lower reaches, a considerable percentage of its heavy sediment load settles out, resulting in a perched river channel whose 100-year flood level is an average of 12 meters higher than the surrounding flat countryside, contained only by levees up to 20 meters high. These levees must be continually raised in order to keep pace with the slow rise of the riverbed.

The Jinjiang levee system can barely contain the river's average annual high flow under these conditions. During large floods, linear kilometers of embankment simply erode away, and the surrounding countryside is flooded for months at a time. Levee repairs are tremendously expensive, difficult and dangerous. Even when the levee system does its job without a breach, the costs due to interruption of production and evacuation of the floodplains is immense when floodwaters are diverted into the designated flood detention areas in order to protect major downstream population centers.

If the Three Gorge Dam is not constructed, all levees would have to be raised between two and three meters in order to contain the historical 1954 flood. This would require a doubling of existing levee fill volume to a total of more than twenty billion cubic meters (Xianyi). If the Three Gorge Dam is built to a 150 meter top of conservation pool, the flood flow diversion areas will still occasionally be used to control flooding from Dongting Lake, the Han River, and periodic very large Yangtze River floods (USBR, 1984).

One of the very significant, but as yet unquantified, benefits of the Three Gorge Dam and Reservoir is a result of the fact that about

seventy percent of all silt in the Yangtze River will settle out in the reservoir, regardless of its final configuration (MWREP, 1983b). The cleaner water discharged from the reservoir will probably retain its residual sediment load in the form of very fine particles until it reaches the Yangtze delta.

It is quite possible that this 'clean' water may reverse the channel deposition process by scouring, thus gradually lowering the elevation of the riverbed and increasing channel capacity. For example, a one-meter degradation of the highly aggraded river channel below Yichang would increase its capacity from 56,700 CMS to about 62,000 CMS, assuming that the existing levee system is properly maintained in its current state. This would greatly increase the ability of the Three Gorge Reservoir to control floods. For example, this enhanced downstream channel capacity would, for the 1954 flood, allow the Three Gorge Reservoir to reduce temporary relocations by half a million, farmland flooded by 70,000 hectares, and total flood damages by about $2.3 billion (Clowes, 1987c).

Regardless of final reservoir configuration or sediment entrapment rate, the riverbed below Yichang will not continue to aggrade at its current rate if the project is constructed. This will lead to large savings in the avoided costs of continual levee raising.

CHINA'S POWER SYSTEM: PROBLEMS AND PROSPECTS

Introduction.

The People's Republic of China possesses the world's largest total energy potential, but its industry is suffering from a severe and chronic lack of energy. One of the causes of this situation is the

series of internal upheavals described earlier in this chapter. However, it now appears that the political situation in China will remain relatively stable for the forseeable future. The government, which recognizes the importance of energy development, is working to provide the electrical energy required to bring China's great potential to fruition.

The Growth of Chinese Electrical Generating Capacity.

Mao Zedong repeatedly referred to the power and transportation industries as the "vanguards" of China's modernization program, and historical statistics have reflected this emphasis. In 1949, following twelve years of continuous war and internal strife, China's total installed generating capacity was 1,850 megawatts, and total national electricity generation amounted to only 4.3 terawatt-hours. The gains made by China's electrical generating industry since that time have been remarkable. Table VIII shows that the country's installed capacity and annual energy generation have expanded at average rates of 11.5 percent and 13.8 percent annually over the last 35 years.

However, these impressive rates of growth have not by any means been consistent. Frequent political upheavals and dramatic changes in Party direction have caused the energy production growth rate to fluctuate violently from year to year. As a case in point, the Cultural Revolution caused energy production to drop 27 percent in 1966. The anti-Confucius campaigns of 1973-1974 and the work stoppages and slowdowns that accompanied the purge of the Gang of Four also caused severe fluctuations (Chu-Yuan, 1984).

TABLE VIII

CHINA'S HISTORICAL INSTALLED ELECTRICAL GENERATING
CAPACITY AND ANNUAL ENERGY PRODUCTION

Installed Capacity (megawatts)			Annual Generation (gigawatt-hours)				
Year	Thermal	Hydro	Total	Coal	Oil	Gas	Hydro	Total
1949	1,686	163	1,849	3,576	22	1	711	4,310
1950	1,763	195	1,958	4,950	46	1	714	5,709
1951	1,844	233	2,077	6,110	70	1	899	7,080
1952	1,928	279	2,207	7,438	88	2	1,359	8,887
1953	2,016	334	2,350	7,531	126	2	1,536	9,195
1954	2,334	441	2,775	8,663	164	2	2,263	11,092
1955	2,701	582	3,283	10,360	218	3	2,450	13,031
1956	3,127	769	3,896	11,236	242	7	3,183	14,668
1957	3,620	1,015	4,635	14,173	335	13	4,814	19,335
1958	5,074	1,214	6,288	22,878	473	78	4,102	27,531
1959	7,114	1,536	8,650	52,455	1,313	252	8,576	62,596
1960	9,975	1,943	11,918	49,797	1,882	317	7,428	59,424
1961	10,314	2,147	12,461	26,330	1,655	290	9,126	37,401
1962	10,664	2,373	13,037	34,255	2,169	349	9,022	45,795
1963	11,111	2,570	13,681	38,345	2,491	371	10,822	52,029
1964	11,576	2,784	14,360	46,415	3,716	429	8,643	59,203
1965	12,061	3,015	15,076	51,649	5,081	463	10,411	67,604
1966	12,999	3,486	16,485	61,224	6,427	565	11,013	79,229
1967	14,011	4,030	18,041	40,007	5,492	480	12,002	57,981
1968	15,101	4,659	19,760	51,537	7,953	738	12,770	72,988
1969	16,276	5,387	21,663	60,846	9,220	892	16,214	87,172
1970	17,542	6,228	23,770	80,408	13,988	1,074	20,392	115,862
1971	19,529	7,261	26,790	87,661	17,366	1,428	24,971	131,426
1972	21,740	8,465	30,205	90,453	19,968	1,870	28,601	140,892
1973	24,202	9,868	34,070	88,222	22,397	2,574	36,335	149,528
1974	26,943	11,504	38,447	93,033	28,578	3,153	41,367	166,131
1975	29,994	13,412	43,406	109,279	35,136	3,836	47,589	195,840
1976	32,956	14,191	47,147	112,128	40,910	4,388	45,704	203,130
1977	35,706	15,744	51,450	127,117	43,469	5,233	47,585	223,404
1978	39,871	17,251	57,122	153,418	52,114	6,380	44,640	256,552
1979	43,922	19,094	63,016	168,042	56,531	7,190	50,187	281,950
1980	45,581	20,288	65,869	176,649	58,119	7,516	58,316	300,600
1981	47,218	21,915	69,133	177,229	59,973	6,526	65,572	309,300
1982	49,422	22,938	72,360	185,265	61,018	7,012	74,383	327,678
1983	52,288	24,157	76,445	196,811	60,859	7,315	86,454	351,439

References: Chu-Yuan, 1976; Jiaping; Clarke; Howe, Christopher; MWREP, 1983a.

Despite these difficulties, China has always been at least 95 percent self-sufficient in energy production. In fact, since 1973, it has been a net exporter of energy. Currently, the country's energy consumption approximately balances energy supply (Chu-Yuan, 1984). However, partially as a result of the country's reluctance to add to its trade deficit by importing large quantities of fossil fuel, China's industrial sector is operating far below its potential capacity.

The Effects of the Chronic Energy Shortage.

In 1980, the World Bank performed a comprehensive study of China's economy as a prerequisite to Bank membership (Ludlow). This study concluded that a lack of energy was the factor most severely retarding Chinese economic development. By 1980, the chronic national energy shortage had caused China's industrial sector to operate at a long-term average of only 70 percent of its full capacity, leading to an estimated annual loss of about $45 billion in industrial output (Chu-Yuan, 1984). The Chinese government is acutely aware of this situation, and is now pursuing a two-step strategy to develop the country's huge energy resources.

The Sixth Five-Year Plan, announced by Beijing in December of 1982, set the growth rate of primary energy consumption at only 1.4 percent, far below the unrealistic projections of previous Five-Year Plans, and also below historical growth rates. As described later in this chapter, figures for energy production and consumption are now outpacing the goals of the Sixth FYP by a wide margin and are expected to exceed projected rates until at least the end of this century.

CHINA'S ENERGY RESOURCES

National Hydropower and Coal Resources.

Introduction. Every developing country requires large-scale non-diffuse sources of energy to power its growing industrial sectors. The only non-diffuse yet renewable source of energy known to man is hydropower. The People's Republic of China possesses one-sixth of the world's exploitable hydropower resources. This hydro capacity, if constructed, would yield 1,923 terawatt-hours (TWh) of energy annually.

Coal. In addition to this rich endowment of hydro resources, China also possesses the world's second largest exploitable reserves of coal. Although this vast resource of nearly two-thirds of a trillion tons of coal has been underdeveloped, it is expected to provide most of China's electrical energy into the forseeable future.

Tables IX and X, respectively, show the distribution of China's exploitable hydropower and coal resources. Table XI depicts China's regional installed hydroelectric and thermal generating capacity and its annual generation. These three tables reveal that, although the People's Republic of China owns the largest energy reserves on earth, they are quite unevenly distributed and unevenly developed throughout the country. The following paragraphs briefly describe each region's endowment of natural water and coal energy resources.

Regional Hydropower and Coal Resource Distribution.

Southwest China. Remote Southwest China, which includes Tibet and Yunan and Guizhou Provinces, has an abundance of hydro potential – more than two-thirds of the national total. This energy could be used to exploit the rich mineral resources of this area; manganese, tin,

TABLE IX

CHINA'S THEORETICAL, EXPLOITABLE, AND
DEVELOPED HYDROPOWER RESOURCES

Region or River	THEORETICAL RESOURCES (megawatts)	EXPLOITABLE RESOURCES		DEVELOPED RESOURCES	
		Installed Capacity (megawatts)	Annual Energy (TWh)*	as of 10/87 (megawatts)	Percent Developed
By Region					
North	12,300	6,920	23.2	905	13.1
Northeast	12,120	11,990	38.4	2,470	20.6
East	30,050	17,900	68.8	5,130	28.7
Central	67,440	64,080	297.4	9,830	15.3
Southwest	469,960	235,700	1,305.0	5,295	2.2
Northwest	84,180	41,940	190.5	3,370	8.0
Nat'l totals	676,050	378,530	1,923.3	27,000	7.1
By River					
Yangtze	268,030	197,240	1,027.5	10,700	5.4
Yellow	40,550	28,004	117.0	4,625	16.5
Pearl	33,480	24,850	112.5	2,560	10.3
NE Rivers	15,310	13,612	44.0	2,805	20.6
SE Rivers	25,050	16,695	61.8	2,350	14.1
SW Rivers	96,900	37,680	209.9	830	2.2
Yalu and other Tibetan Rivers	159,740	50,479	296.8	950	1.9
Inland R.	36,990	9,970	53.8	2,180	21.9
Nat'l totals	676,050	378,530	1,923.3	27,000	7.1

* One terawatt-hour equals 1,000 gigawatt-hours.
  References: Cao; Cheng; Chu-Yuan, 1984; Corps, 1982a; Jiayang;
              Jiazheng; Jing, Hua; MWREP 1983a, 1983b, and 1984;
              Shi, Jiayang; Smil, 1981 and 1983; and Wu, Xiutao.

TABLE X

CHINA'S RECOVERABLE COAL RESERVES

PROVEN REGIONAL COAL RESERVES

Province or City	Reserves (billion tonnes)	Province or City	Reserves (billion tonnes)
Northwest China		**Northeast China**	
Ningxia	29.28	Heilongjiang	10.94
Shanxi	21.07	Liaoning	7.06
Xinjiang	16.38	Jilin	1.97
Gansu	6.04		——
Qinghai	4.32	Regional total	19.94
	——		
Regional total	77.09	**Central China**	
		Henan	17.49
North China		Hunan	2.86
Shanxi	200.97	Guangxi	1.99
Nei Monggol	193.12	Guangdong	0.81
Hebei	14.17	Hubei	0.51
Beijing	2.58		——
Tianjin	0.50	Regional total	23.67
	——		
Regional total	411.34	**Eastern China**	
		Anhui	22.31
Southwest China		Shandong	13.39
Guizhou	46.25	Jiangsu	3.98
Yunnan	15.50	Jiangxi	1.15
Sichuan	6.84	Fujian	0.83
Xizang (Tibet)	0.04	Zhejiang	0.14
	——		——
Regional total	68.63	Regional total	41.80

Total national recoverable reserves of coal - 642.48 billion tonnes.

References: Chu-Yuan; MWREP, 1983b.

TABLE XI

CHINA'S REGIONAL INSTALLED CAPACITY COMPOSITION
AND ELECTRICITY GENERATION, 1983

Region	Installed Electrical Generating Capacity (megawatts)				
	Thermal	(percent)	Hydro	(percent)	Total
North China					
Power network	9,132	92.8	708	7.2	9,840
Entire region	10,435	92.8	810	7.2	11,245
Northeast China					
Power network	8,099	79.9	2,037	20.1	10,136
Entire region	9,306	80.8	2,211	19.2	11,517
East China					
Power network	9,088	83.7	1,770	16.3	10,858
Entire region	16,476	78.2	4,593	21.8	21,069
Northwest China					
Power network	2,543	53.6	2,201	46.4	4,744
Entire region	3,850	56.1	3,013	43.9	6,863
Southwest China					
Power network	2,318	47.7	2,542	52.3	4,860
Entire region	3,548	42.8	4,741	57.2	8,289
Central China					
Power network	5,423	63.4	3,131	36.6	8,554
Entire region	8,662	49.6	8,801	50.4	17,463

Region	Annual Generation (gigawatt-hours)				
	Thermal	(percent)	Hydro	(percent)	Total
North China					
Power network	53,649	97.9	1,151	2.1	54,800
Entire region	59,779	97.9	1,282	2.1	61,061
Northeast China					
Power network	48,389	90.2	5,257	9.8	53,646
Entire region	53,890	90.4	5,723	9.6	59,613
East China					
Power network	52,290	90.1	5,745	9.9	58,035
Entire region	84,592	86.1	13,656	13.9	98,248
Northwest China					
Power network	10,235	48.3	10,955	51.7	21,190
Entire region	14,559	53.2	12,807	46.8	27,366
Southwest China					
Power network	10,572	49.8	10,656	50.2	21,228
Entire region	15,155	47.2	16,953	52.8	32,108
Central China					
Power network	24,693	60.9	15,853	39.1	40,546
Entire region	36,873	50.9	35,570	49.1	72,443

References: Chu-Yuan; MWREP, 1983a.

titanium, vanadium, zinc, copper, lead, bauxite, and others (MWREP, 1983a). Upon completion of the national transmission grid, it will be possible to transmit large blocks of cheap hydropower energy to the heavily populated and industrialized eastern region of the country.

Northwest China. Northwest China is also rich in mineral resources, including vanadium, tin, and zinc (MWREP, 1983b). The population and heavy industrial development in this region is relatively sparse, so its exploitable hydro potential of about 42 million kilowatts could be used primarily for minerals processing.

North China. North China possesses most of the country's vast coal reserves, but has very few exploitable hydropower sites. Currently, large quantities of coal are shipped long distances to population centers at great expense. As other areas develop their hydro resources, the amount of coal that is transported and burned will decrease. China plans to build large thermal plants in this area, while using scarce hydro plants for peaking (Smil, 1983). The possibility of installing pumped-storage hydro is also being investigated.

Northeast China. Northeast China possesses a well-balanced blend of exploitable coal and hydro resources. Since many of its most economical hydro sites have already been developed, future plans call for the construction of large thermal plants to cover anticipated load growth.

Central China. Central China is heavily populated, and the region's power demand is growing rapidly. Currently, coal-fired thermal plants provide most of the area's energy. Hydropower is being

developed at an accelerated pace, including the Gezhouba project, whose final generating units will come on-line in 1988. The Three Gorge project will be located in Central China's Sichuan Province.

East China. East China is the most heavily-populated area in the country, but is quite poor in terms of energy resources. The needs of this region in the future will be met mainly by importing power from other areas (Shi, Jiayang). Since East China has the heaviest concentration of industry and population in the country, the construction of the Three Gorge Dam is essential for the economic development of the middle and lower Yangtze valley. The major population and industry centers of Beijing to the north, Chongqing to the west, Canton to the south, and Shanghai to the east are all located within a thousand kilometers of transmission distance of the Three Gorge power station (USBR, 1984).

CHINA'S STRATEGY FOR ENERGY RESOURCE EXPLOITATION

Overview of the Strategy.

A comprehensive study has shown that a developing country's power output growth rate usually outpaces its industrial production growth rate by a factor of from 1.3 to 1.4 (Clarke; Smil, 1978). In China, from Liberation in 1949 to 1975, this factor has ranged from a minimum of 1.3 to a maximum of 1.6. It is reasonable to expect that the growth of industrial and agricultural production will proceed at a rate of eight percent until at least the turn of the century. This would require an installed capacity growth rate of about eleven percent, which is approximately equal to China's historical growth rate over the past 38 years.

In order to maintain this growth, China will aggressively exploit its enormous reserves of coal and hydro. The efficiency of the existing power system will be improved by reducing line losses, improving maintenance, and converting old, inefficient oil-fired plants to more efficient coal-fired plants wherever possible. Finally, the national government intends to reap the benefits of technology exchange with other nations regarding nuclear power, high-voltage transmission, and very large hydro (MWREP, 1983a).

The main points of this plan are described in the following paragraphs.

POINT 1: Develop Hydropower Resources.

The Construction of New Hydropower Plants. Currently, the installed capacity of existing Chinese hydro plants and those under construction equals only 30 thousand megawatts, but plans call for this total to increase to 80 thousand megawatts by the year 2000. These plants would produce an average of 250 terawatt-hours (TWh) of energy annually (Wu, Xiutao).

As it constructs these plants, the Chinese government will apply its policy of 'walking on two legs' on a national scale. One 'leg' will be cascades of large hydro projects that will provide the power for industrial and population centers. Most of these proposed cascades are located on the Yangtze River and its largest tributaries, as described in Appendix A. The other 'leg' is small hydro, defined by the Chinese government as plants with an installed capacity of 12 megawatts or less (Jing, Hua). These small stations will provide energy to rural homes and industry. The general principles of the

Chinese strategy for developing these two hydro 'legs' is described below.

The Development of Large Hydropower Systems. The Chinese are accelerating development of entire river basins for multiple purposes, including hydropower. Particular attention is being given to the Yangtze River basin, which possesses five times the exploitable potential of any other river in the world. As of mid-1987, 21 large hydro plants are in place on the Yangtze, and three more are under construction. The total capacity of these plants is about 10,700 megawatts. Appendix A includes pertinent data on existing and planned large Yangtze River hydropower plants.

China now possesses 133 large hydro plants with an installed capacity of 12 or more megawatts. 43 such plants are currently under construction, including 26 with installed capacities of 250 megawatts or more (Wu, Xiutao).

The Development of Small Hydropower Stations. China's exploitable small hydropower potential is about 71,300 megawatts. This potential is distributed in a more equitable manner than China's large hydro resources; nearly half of the country's 2,200 counties have at least ten megawatts of small hydro potential (Hangzhou). Small hydro has emerged as a favored method of rural electrification, and progress has been exceptional. Rural small hydro capacity has recently been increasing at a rate of about 1,000 megawatts per year.

As of 1987, China had more than 70,000 small hydro stations on line, with a total installed capacity of about 8,100 megawatts, which is nearly equal to the capacity of her large hydro stations (see Table

TABLE XII

CHINA'S CURRENT SMALL HYDROPOWER DEVELOPMENT AND POTENTIAL

Region	Exploitable Small Hydro Potential		Developed Small Hydro	
	Megawatts	Percent	Megawatts	Percent Developed
Southwest	33,392	46.8	1,784	5.3
Northwest	9,361	13.1	512	5.5
Central	15,542	21.8	3,445	22.2
Eastern	9,424	13.2	1,952	20.7
Northeast	1,953	2.8	169	8.7
North	1,641	2.3	218	13.3
NATIONAL TOTALS	71,313	100.0	8,080	11.3

References: Jing, Hua; Xiaozhang.

XII). The combined average annual energy output of these plants is about 17.2 TWh (MWREP, 1983a). The potential for further development is great, because only about eleven percent of the small hydro potential in China has been developed, and many exceptionally good sites remain unexploited at this time.

About 38% of China's total energy consumption occurs outside of its major centers of industry and population. Agriculture, local industries, and households annually consume about 250 terawatt-hours of the energy produced by hydro and fossil fuel plants (Clarke; Smil, 1978).

This consumption is divided into categories roughly as follows;

* county-run industries - 46%
* light industry and processing - 23%
* irrigation and drainage - 22%, and
* commune-run industries, 9%.

Currently, small hydro contributes about eighteen percent of this power (Xiaozhang).

Small hydro benefits county- and town-run industry, agricultural production, and peasant quality of life. The ultimate goals of the rural electrification program are to provide power to ninety percent of the rural population for lighting and television, and power to twenty percent of all households for water heating and cooking. This could be accomplished if energy to rural areas could be increased by 22 percent. Currently, many cooking and heating fires are stoked with grass and dead or live wood, leading to the denuding of vast land areas and contributing to the loss of five billion tons of topsoil per year (Chu-Yuan, 1984).

Eventually, the rural population of 800 million is expected to consume an average of 200 kilowatt-hours per year of energy per person and will require an average installed capacity of 100 watts (Hangzhou). In addition to small hydro, rural areas are being encouraged to take advantage of their other indigenous energy resources, including coal, wind, and geothermal.

The philosophy behind all of these small plants is called the "Three Selfs" - self-construction, self-management, and self-operation (Deng). Provincial and county governments assist with grants, technological expertise, and raw materials. The use of local materials and labor result in a very low investment cost for small hydro - about $800 to $900 per kilowatt, about equivalent to that of the largest Chinese hydro plants (Jing, Hua). Additionally, the production cost of electricity produced by small hydro plants is quite low, ranging from 2.5 to 3.5 cents per kilowatt-hour (Xiaozhang).

POINT 2: Develop Coal Resources.

Current Coal Production. Raw coal production in 1983 was 666 million tons, third largest in the world (MWREP, 1983a). About 58 percent of this total was produced by 580 medium and large mines operated by the Ministry of Coal Industry. Provincial, county, or city mines produce about 26 percent, and the remaining 16 percent is contributed by people's communes (about 100 million tons annually). More than 95 percent of all coal in China is mined underground (Jing, Wu).

Currently, about two-thirds of China's electrical energy is generated by coal-fired thermal power plants, mostly at 65 large thermal power stations with a capacity of 250 megawatts or more (MWREP, 1983a). Thermal power plants will be expected to produce 953 terawatt-hours of energy annually by the year 2000. If this increased demand is to be met mostly by constructing new coal plants, as national policy implies, the demand for coal will expand to 1,070 million tons annually by 2000 (MWREP, 1983b). In order to meet this demand, output must increase by 11 million tonnes per year from 1984 to 1990, and by 34 million tonnes annually thereafter until the turn of the century (USBR, 1984). It is expected that increases in coal production will be evenly divided between existing deep mines, smaller local mines, and new ocean and deep mines. Despite these increases, a shortfall of 90 million tonnes of annual coal production is anticipated by the end of the century.

Problems and Solutions: General. Coal has been the backbone of the Chinese electrical power industry since pre-Liberation times, and

will continue to produce most of China's energy for at least the next thirty years. Therefore, Zhou's "Grand Plan for Coal" will be the blueprint for China's future energy plans. In order to achieve the goal of efficient exploitation of its coal resources, China will address the basic problems described in the following paragraphs.

Problem: Railway Saturation. The vast majority of China's coal reserves are located in its remote northern regions, more than 2,000 kilometers from major population and industrial centers. This separation of resources and load centers has resulted in coal accounting for forty percent of all freight tonnage - 400 million tons - shipped on Chinese railways today (Chu-Yuan, 1984).

The rail lines connecting mines and load centers have reached conditions of saturation or near-saturation. For example, the Jingpu rail line running from Xuzhow to Nanjing has a capacity of 45 million tons per year. It is now at 95 percent capacity, and coal accounts for 67 percent of all tonnage shipped. The Jingqwuang rail line north of Wuhan has a saturation capacity of 40 million tons annually. It is now at 88 percent capacity, with 65 percent of its cargo consisting of coal (MWREP, 1983b). In recent years, up to 30 million tonnes of coal have been piled along rail lines in Shanxi because the rail lines did not have the capacity to ship it. The necessary future increases in coal production will require the construction of more railroads specifically for coal transportation, a step the Chinese government is reluctant to take in the forseeable future.

The Chinese government has recognized this problem and is pursuing several remedies to relieve transportation bottlenecks. The unit train

concept, unknown in China until recently, is now being implemented in stages. It will follow the North American concept, where unit trains of 10,000 tons or more carry coal in permanently coupled cars of 100 to 120 tons capacity each, and travel back and forth between coal mines and power stations on private lines (Kloss). As a rule, hopper or gondola cars with a capacity of 33 to 65 tons have been used in China, and trains have had a capacity of no more than 3,300 tons. The loading and unloading of coal is also now being mechanized on a large scale (Smil, 1983).

In addition to these steps, large coal plants will be constructed in the vicinity of the large mines in Shanxi and other provinces, in support of the theory that electricity is easier to transmit than coal. Unfortunately, a penalty in the form of substantial line losses must be expected during the transfer of large blocks of electricity more than 2,000 kilometers to major load centers in the South and East. Apparently, the national government assumes that this disutility will be outweighed by relieving the great stress on the overworked rail system.

Problem: Inefficient Consumption. The two main thrusts of the Chinese energy program are greater production and widespread conservation. Conservation programs could yield significant savings in many current areas of inefficient operation;

* Railroads. Currently, inefficient steam engines consume about 24 million tons of coal annually in China, accounting for 80% of all energy consumed by the transportation sector. The government has launched a program whose objective is to replace old, inefficient steam locomotives with diesel and electric engines. By the end of the century, about 15,000 kilometers of existing trunk lines will be electrified (Clarke; Smil, 1978; Kloss).

* **Mining.** Presently, one-third of Chinese coal is produced by small local mines, only one-fifth of which are mechanized. Coal is extracted with dynamite, pick and drill, and is loaded onto carts with shovels. The current output of coal in China ranges from 0.7 to 2.0 tons per man-day, a fraction of the 10 to 30 tons per man-day in United States mines, which are almost entirely mechanized (Smil, 1983). The Sixth Five-Year Plan called for an increase in average coal mining efficiency from 0.912 tons per man-day for all mines in 1980 to 0.965 tons per man-day in 1985 (Beijing).

* **Oil-Fired Plants.** Except in remote areas, oil- and gas-fired thermal plants will no longer be constructed. Oil-fired plants are expensive to run, and Chinese oil production may have already peaked (Chu-Yuan, 1984). All of the existing 7,780 megawatts of oil-fired generating capacity should be converted to a coal-fired mode at the earliest opportunity, if feasible (Qin). Unfortunately, this portion of the conservation program may become bogged down by high costs: plants designed to burn oil cost about $90 to $100 per kilowatt of installed capacity to convert to a coal-fired configuration (Bao).

* **Industry.** The efficiency of large, basic industrial operations will be improved. For example, China now uses four times as much coal to produce a unit weight of steel as does the United States or Japan, and twice as much coal as the United States, Japan, France, or the Netherlands to produce a unit weight of nitrogen fertilizer (Clarke). About half of China's coal burners operate at an efficiency of about 40 to 50 percent, compared with an average efficiency of about 80 percent in the United States. Some steel mills in China burn coal at efficiencies as low as eight percent. Since heavy industry consumes about 160 million tons of coal annually, any industry-wide improvement in coal-burning efficiency will lead to great savings (OTA).

* **Use of Hydropower.** The most efficient way of preserving coal resources is to displace coal-fired steam generation with hydropower generation. If Three Gorge Dam power were used solely to displace coal-fired energy, the transportation and burning of 35 million tons of coal annually would be avoided.

* **New Coal Plants.** Medium-sized (300 to 500 megawatt) coal plants will be constructed at load centers such as ports and cities, if rail or river coal transportation facilities are adequate. These high-temperature, high-pressure plants will be built with the best available world technology. The Seventh Five-Year Plan (1986-1990) will also construct larger, 'key' coal-fired thermal plants at mine mouths (Li, Peng).

* Cogeneration. The hundreds of small, inefficient coal plants currently located in cities and industry will be the targets of an aggressive campaign aimed at converting them to cogeneration plants. Currently, the nation possessed 4,920 megawatts of cogeneration capacity, which supplied 80 trillion kilocalories of heat in 1983. The larger cogeneration plants are usually located in industrial regions and in large Northern cities (MWREP, 1983a).

* Home Heating. One-third of China's raw coal is consumed for residential heating, which is the most inefficient and polluting of all coal uses (Clarke). It remains to be seen whether or not the distribution of energy from centralized sources to widely-spread rural areas will incur unacceptable efficiency losses.

POINT 3: Develop Nuclear Technology.

The pragmatic Chinese have few qualms about nuclear energy. Official policy concludes that it has "outstanding merits" and is "basically a clean energy resource" (Smil, 1978). There is some disagreement among experts in China's nuclear industry, however. In the past few years, many Chinese experts have been exposed to the prevailing worldwide sentiment that is running generally against nuclear power. For instance, a Worldwatch Institute member, after visiting the State Planning Commission's Economic Institute, stated in a published article that nuclear power was "not a technology appropriate to China" (Yang).

The transportation of coal or electricity from the North over vast distances to the South and East will be extremely expensive. As an example, 500 kV transmission lines cost about $750,000 per kilometer to construct (Farr). Since Northeast China, East China, and Guangdong Province are short of both coal and hydropower resources, the government plans to augment power supply in these areas by constructing a limited number of large pressurized water reactor (PWR) plants.

China's first nuclear power station, the 300 megawatt Qinshan station near Shanghai, is nearing completion (Chen, Nai-Ruenn).

Although China has not released figures on its uranium reserves, outside sources estimate that the country possesses 20 to 100 thousand tons of high grade uranium. This estimate is based on various statements by the government, including the official claim that uranium reserves are sufficient to supply the needs of 15,000 megawatts of nuclear power station capacity for 30 years (MWREP, 1983b).

POINT 4: Upgrade the National Power Transmission System.

The Current Status of China's Transmission Systems. In addition to seven provincial transmission grids, Northwest, Southwest, North, Central, Northeast and East China now possess regional transmission grids. The capacity and coverage of these systems are shown in Table XIII. The South China grid, which will include Guangdong and Guangxi Provinces, will be constructed in the near future. The present system transmits power at 66, 110, 154, 220, 330 and 500 kilovolts, and distributes it at 220 and 380 volts, 50 cycles per second (Clarke).

At the end of 1984, only about 6,000 kilometers of 330 kV and 500 kV lines existed in China. Approximately 2,500 kilometers of such lines were under construction, and 4,200 kilometers were planned. The 1,200 megawatt HVDC line from Gezhouba Dam to Shanghai, which was begun in early 1986, is expected to be complete in late 1987 (EW, 1986).

Existing Problems. All Chinese transmission systems are government-owned, which should somewhat simplify the construction, operation and maintenance of a unified national network. However, In order to effectively transfer large blocks of power from the proposed

TABLE XIII

CHINA'S REGIONAL AND PROVINCIAL TRANSMISSION GRIDS

Region	Area Covered	Grid Capacity (Megawatts)	Annual Power Transmitted (Gigawatt-Hours)
REGIONAL GRIDS			
Northeast	Liaoning and most of Jilin and Heilongjiang	7,759	42,350
East	Shanghai, Jiangsu, Anhui and Zhejiang	7,455	42,390
Central	Henan and Hubei	5,529	24,810
North	Beijing, Tianjin, Shanxi and northern Hebei	4,989	25,890
Northwest	Shaanxi, Gansu, and most of Qinghai	3,832	25,890
Southwest	Sichuan and Guizhou		
PROVINCIAL GRIDS			
	Seven large grids	14,204	68,170
Percent of National Total		69.5%	78.0%

References: Chu-Yuan, 1984; Wang, Ping-Yang.

large coal and hydro stations to rapidly growing industrial centers, several basic shortcomings in the Chinese national transmission system must be corrected;

* existing grid interconnections possess inappropriately low ratings, which do not allow flexible operation of the Chinese power system. For example, the large Northeast and North grids are connected by only a single 110 kV line. Therefore, if there is a power shortage in an area which has inadequate indigenous energy resources, that area must curtail large, energy-intensive industrial operations.

* these existing interconnections are frequently overloaded,
leading to system frequency and voltage fluctuations that may
be damaging to electical machinery. This situation indicates
that the demand for electricity in many areas far exceeds the
available supply (Clarke).

* undersized and inefficient intragrid transmission lines now
waste about five billion kilowatt-hours of energy annually
(Chu-Yuan, 1984).

Proposed Remedies to These Problems. In order to more efficiently
transfer its growing and unevenly distributed energy supply, China will
pursue a program of extra-high voltage transmission line construction
and upgrading. To kick off this program, 5,640 kilometers of 500 kV
line were built during the 6th Five-Year Plan (Chen, Nai-Ruenn).

As described earlier in this chapter, coal and hydro resources are
located primarily in the North and West of the country, and major loads
are located in the Southeast and Central regions. The transmission of
energy rather than coal is more efficient in terms of energy saved, and
will remove much of the strain from the overloaded national rail
network.

POINT 5: Diversify the Exploitation of Energy Resources.

While the energy demands of the large load centers will be
primarily satisfied by the construction of huge powerplants and large
transmission grids, the large rural areas, which include tens of
thousands of small communes and villages, will continue their policy of
reliance on local energy resources, such as small hydro, solar,
geothermal, and biomass. This emphasis on renewable resources is
mandatory, since the cost of constructing an energy distribution system
to reach all rural areas would be prohibitive. Additionally, China
would like very much to continue her energy self-sufficiency, and

allowing the countryside to support itself is a giant step in this direction.

NAVIGATION THROUGH THE THREE GORGES

Navigation on the Yangtze River.

The Yangtze has for centuries been the major riverborne artery of commerce in China, and today serves as the main link between Shanghai at the coast and the rich agricultural and industrial resources of Sichuan Province. The river is navigable from its mouth to Yibin, which is 2,800 river kilometers upstream. However, navigation is currently restricted and dangerous in the Three Gorges. Between Gezhouba Dam and Chongqing, there are more than 150 dangerous rapids and numerous shoals (ENR, 1984). Traffic is one-way in areas where the channel is only 110 to 330 meters wide (USBR, 1984). At this time, vessels can travel through the Gorges only under the most favorable weather and flow conditions. Currently, towing capacity in the Chongqing-Yichang reach of the Yangtze is about one ton per horsepower, only ten percent that of the lower reaches (MWREP, 1983b).

The creation of a lake at a normal reservoir water surface elevation of 180 meters would provide a deep and narrow reservoir from the Three Gorge Dam to the port of Chongqing, 603 kilometers upstream, for vessels of up to 5,000 tons deadweight. The width of the reservoir backed up by the Three Gorge Dam will be 170 to 1,000 meters, or, on the average, only twice as wide as the river in its present state, due to the steepness of the Gorge walls (Savage; USBR, 1984).

Current Studies.

As in many other countries, most major Chinese cities were founded

on rivers because they were the major trade routes of the day. After the construction of extensive road and rail systems, many canals (including the Grand Canal) fell into disrepair. In the latter half of the 20th century, this process has been reversed, and the movement of goods by inland waterway has become much cheaper than by any other mode.

The Chinese government is now turning its attention towards navigation through the Three Gorges. The Ministry of Communication's Administration of Navigational Affairs of the Changjiang River is now investigating the specifics of potential fuel and time savings that the Three Gorge Dam would bring under several different configurations on the reservoir itself (Yan). The MOC's Bureau of Inland Water Transportation, which oversees Yangtze River navigational planning (to include ports), is defining how the Three Gorge Dam would fit into overall Yangtze Basin navigational planning (Zhang).

The Changjiang National Shipping Corporation (the MOC's shipping company) is designing the vessels that will ply the new reservoir for maximum fuel efficiency and for best operation in the Three Gorge and Gezhouba locks and shiplifts (Zhou). Finally, the MOC's Navigation Office for the Three Gorge Project is examining the variety of effects the Three Gorge Dam will have on overland and downstream transportation modes (Shi, Heng).

Navigation Improvements.

General. Inland waterways may be improved by one or more of three methods. An existing channel may be cleared or deepened, a series of reservoir with locks may be constructed, or a separate canal may be

excavated along whatever route the builder desires (James). The first two methods are of interest in this study, and are described in the following paragraphs.

Open-Channel Improvement. This is the least costly method of improving navigation conditions on an existing channel. It consists of dredging to deepen a channel, removing snags, rocks, and other obstructions, and augmenting low flows with upstream reservoir releases. Reservoir flows will add flow volume to very low flow periods, thereby alleviating channel sedimentation problems which are caused by very low flows. Annual operation and maintenance costs may include the removal of ice jams by blasting or other methods. The costs of contraction works, which direct river water into the center of the channel for scouring, must be considered. Bank stabilization and channel cutoffs may also be required.

Due to the exceptional navigation difficulties in the Three Gorges, the Changjiang River Administration of Navigational Affairs has eliminated more than 100 major reefs and shoals and has installed about 2,000 electric navigation lights and buoys between Yibin and Yichang at a cost of more than $3 billion, so that shipping can go on both day and night (Liu; Yan).

At the beginning of the 20th Century, the 650 kilometer trip from Yichang to Chongqing took up to a year to complete. Due to improvement in vessels and the efforts of the national government, the same trip, though still hazardous, takes about three to five days (Carpenter).

Construction of a Series of Reservoirs and Locks. A series of reservoirs will form a stairstep of lakes and will also store water for

the augmentation of low flows downstream. An ideally-sized single-purpose navigation reservoir would store enough water to support an amount of low-flow augmentation so that the marginal cost of an additional amount of storage would be equal to the marginal savings in transport costs that would result.

This method is more expensive than open-channel navigation, because of the large capital costs of dams and locks. Other costs will probably include the loss of productivity of flooded land, relocations of roads, railroads, and utilities, and possible degradation of water quality. On the other hand, operation of vessels in slackwater lakes is more economical, and the maintenance costs of existing downstream open channel reaches will become lower.

Lock size and capacity must be carefully planned in order to meet navigation season demand. Allowance must be made for a reduction in system capacity due to mechanical failure of vessels or locks, ice, congestion in the immediate vicinity of the locks, or adverse weather or channel conditions. The capacity of the entire system is reached when the expense of enlarging the locks to relieve congestion exceeds the expected benefits in terms of lower vessel operating costs. Such an analysis was recently completed for the Bonneville Lock on the Columbia River.

THE THREE GORGE PROJECT: STORAGE FOR FUTURE IRRIGATION SCHEMES?
General Principles.

From an agricultural standpoint, the objectives of flood control and irrigation projects are identical: to bring cultivable land to optimum moisture conditions for crop growing. Water may also be

applied to crops in order to cool them during hot periods, to reduce frost damage during cold periods, to aid plant germination, or to help control certain pests.

As the size of irrigated areas grows in developing countries, methods of water collection tend to evolve from small diversion dams and wells constructed and paid for by individuals, to vast government-financed complexes of reservoirs and groundwater wells delivering hundreds of cubic meters of water per second.

Irrigation Water Sources.

Reservoirs. Most of the world's irrigation water is drawn from man-made reservoirs. In some cases, water is released from a storage reservoir and is then removed from the pool upstream of a downstream diversion dam. After being removed from a reservoir or diversion dam, water may be transported to farm headgates by canals or pipelines. Canals may be lined or unlined. Although lined canals are more expensive, they reduce water loss, rodent damage, and maintenance costs. Pipelines are expensive, but reduce operation and maintenance costs, keep water losses to an absolute minimum, and present no safety hazard to children or animals. They have a further advantage over canals in that they require no permanent land purchases (James).

Groundwater Aquifers. The most common alternative to a large storage reservoir is a system of wells that tap a groundwater aquifer. In order for aquifer pumping to be economically feasible, an aquifer must possess the following qualities;

* it must contain water of suitable quality for irrigation;
* it must extend under or near the area to be irrigated;

* its water must be at a depth that does not require excessive
  pumping lifts and accompanying energy expenditure, and
* the aquifer material must be porous enough to transmit water
  at a satisfactory rate.

Some groundwater sources contain more salt than the 30 parts per thousand of seawater, and desalinization in these cases, at about one dollar per cubic meter, is obviously uneconomical for irrigation. Desalinization may be economical for brackish water of 3 parts per thousand or less.

It is critically important that the average pumping rate from the aquifer not exceed the natural recharge rate, which may be assisted with artificial recharge. The capacity of even the largest groundwater aquifers is limited. Therefore, if total natural and artificial recharge rates are not sufficient to meet anticipated demand, groundwater 'mining' occurs and agricultural development must inevitably be curtailed at some future date. This situation is occurring in the United States' midwestern High Plains, because the underlying Ogalalla Aquifer has been heavily mined (McGinnis). On the West Coast, the San Jouquin Basin receives one-eighth of its annual water supply from aquifer mining - a total of about 1.85 cubic kilometers per year (Biswas, 1983a). Mining may be justified if the total discounted future cost of pumping is less than the total discounted future value of the water.

Irrigation Water Distribution Systems.

In the large distribution systems upstream of the farm headgate,

water losses range from two percent for a new, all-pipe system to 40 percent or more for long, unlined open ditches. These losses depend not only upon conveyance construction, but also upon the length of the system, soil conditions, and evapotranspiration. Water losses between the farm headgate and the crops range between 20 and 90 percent, with 50 percent taken as a typical average for a well-managed farm (James). Losses depend upon the method of irrigation, soil conditions, surface runoff, deep seepage, and evapotranspiration by phreatophytes.

Since evaporation rates cannot be generalized, they must be estimated for each specific project. All distribution systems, both project and on-farm, should be designed for the amount of transport efficiency that would allow the marginal value of the water lost to equal the net marginal cost of improving the systems to reduce the losses.

In some cases, excessive seasonal rainfall or ground conditions may require that a drainage system be built to remove excess water from irrigated lands in order to prevent salt buildup or lengthy periods of saturation that lead to crop damage.

On a worldwide basis, irrigation accounts for about eighty percent of all consumptive (non-return) water use, bacause common food crops require vast quantities of water for optimal growing conditions. For example, one kilogram of grain needs about one cubic meter (1,000 kilograms) of water to reach maturity, and rice requires twice this amount (Corps, 1982a; Biswas, 1983).

Irrigation Project Sizing.

Seasonal low flows limit the dependable supply of fresh water for

irrigation purposes unless the water is drawn from a seasonal storage reservoir or dependable groundwater aquifer. Firm yield is the amount of water that can be withdrawn from a stream for irrigation during the driest streamflow year on record. Firm yield may also be defined as the amount of water that can be withdrawn from a stream during a specified severity of drought, according to an acceptable risk of shortage (Kuiper).

Secondary water is available during a smaller percentage of time than firm water. The value of secondary water is equal to the value of firm water less the cost of a supplementary supply or the amount of benefit lost during service interruptions, whichever is smaller. The value of secondary water increases with the percentage of time it is available. When the supply of secondary water fails, those who were using it will either have to obtain an alternate water supply or suffer losses.

On-Farm Irrigation Methods.

After the individual farmer takes possession of irrigation water at his headgate, he may apply it by one or more of the following means;

* flooding. This method consists of flooding a parcel of land to a uniform depth within an area bounded by low dikes.

* furrowing. Water is allowed to flow along shallow trenches between crop rows.

* sprinkling. Water is applied by linear or center-pivot sprinklers. This method reduces water losses to a minimum and is well-suited for use on pervious or shallow soils. In some humid areas where major land preparation costs are not justified, sprinkling has become the most popular method of land irrigation.

The Benefits of an Irrigation Project.

The Evaluation of Irrigation Benefits.   The benefits of an irrigation project are usually set equal to the increase in net farm income due to more intensive cultivation, higher-value crops, and expanded acreage, in addition to secondary benefits in net income (Howe, Christopher).   In other words, these benefits are equal to the difference between farm income with and without the project works (canals, pipelines, and distribution systems) (Kuiper).

The primary economic analysis involved in an irrigation benefit study is an assessment of cropping patterns with and without the irrigation project.   The without-project pattern may be assumed to be the current pattern, unless substantial changes in farming practices are anticipated.   If it is anticipated that a more expensive source of water will be used if the project is not built, the cropping pattern with this source should be used for the without-project condition, and the project will accrue higher benefits, because it will replace this more expensive source.   In humid areas, the with- and without-project cropping patterns may be nearly identical, but they will probably be vastly different in arid areas or areas currently used primarily for grazing (James).

It is logical to assume that a farmer will grow only a few different crops which will maximize his net income, taking into consideration local soil and climate conditions, marketing practice, and farming methods.   The best estimate of crop patterns can be developed from those in similar nearby irrigated areas, adjusted for local practice and conditions.

Farm budgets are used to estimate crop income as a function of yield. Separate budgets are needed for each crop and may be required for the same crop in different soil types. Yields in the absence of the irrigation project can be set equal to those under dry farming conditions. Yields with the project depend on the amount of water applied.

Each crop must receive its optimum amount of water in order to attain maximum yield. Some or all of this consumptive use can be supplied by precipitation. Not all precipitation contributes to crop moisture supply, because some will run off during intense storms. The moisture that does contribute to plant growth is estimated to be the difference between average precipitation on a plot of land and the recorded runoff, obtained from nearby rainfall and runoff guages.

The shortfall can be provided by irrigation. However, it is never economical to make up the full difference between precipitation and optimum water application with irrigation, because the yield for each additional increment of water applied as it nears the optimum amount will approach zero. Therefore, some balance must be struck. Irrigation should cease when the cost of applying the next increment of water exceeds the value of the crop yield that results.

In the United States, crop water requirements for a specific area may be obtained from the Soil Conservation Service of the Department of Agriculture. This information is in the form of yield vs. applied water curves for small, instrumented test plots. The values of water and crop yield may then be compared in order to determine the cutoff point for water application. These curves vary from place to place,

since the distribution of plants, soil types, and climatic conditions is heterogeneous (Howe, Christopher).

Full agricultural development seldom takes place immediately upon the completion of an irrigation project. The construction of the main hydraulic works is followed by an agricultural development period of years or decades before full production in project areas is realized. If a high discount rate is anticipated, it may be impossible to economically justify any irrigation project which has a full production lag period of more than a few years.

The Costs of an Irrigation Project.

Overview of Costs. The annual costs of an irrigation project include interest and amortization on the construction of water delivery and drainage facilities, operation and maintenance of the system, and additional equipment and materials that may be necessary to support the anticipated greater crop yield. Those costs common to most large irrigation projects are listed below (Howe, Charles);

* Direct Tangible Costs.

    * construction costs, including all water conveyance systems to each farm headgate;
    * the present value of all anticipated drainage costs, even if drainage will not be necessary for several years;
    * system operation and maintenance costs;
    * the loss of consumed (non-returned) water to other uses downstream, especially the reduced generation of hydropower;
    * the energy costs of pumping from a reservoir or groundwater aquifer, as shown in Table XI;
    * increased on-farm production costs, including livestock, seed, fodder, fertilizer, fences, building maintenance materials, equipment operation and maintenance, and taxes; and
    * increased on-farm financial costs, including hired labor, interest and amortization on capital, and investment in buildings, new machinery, and the original purchase of the land.

* <u>Indirect Tangible Costs</u>.

  * increased costs of storage or the subsidization of shipment overseas to handle resulting surpluses.

* <u>Intangible Costs</u>

  * the introduction or aggravation of waterborne diseases;
  * land salinization and waterlogging;
  * erosion;
  * aquatic weed growth;
  * loss of freshwater migratory fish and birds; and
  * loss of net income to agriculture and related agribusinesses in non-project areas, when the present project displaces them through the depression of prices or the filling of production quotas.

<u>Irrigation Energy Costs</u>. Irrigation operations, in addition to consuming great amounts of water, are extremely energy intensive. Some areas of Third World nations have an ample supply of water for irrigation, but must drastically downsize their projects, and therefore agricultural production, due to a severe and chronic lack of energy and/or transmission facilities. Table XIV shows typical energy requirements for various types of irrigation.

Upstream reservoir diversions for irrigation purposes also bear a significant energy cost, because most of this water is not available for power operations. For example, if an average annual flow of 1,000 meters per second is diverted from the Three Gorge Reservoir, annual energy foregone at 3.5 cents per kilowatt-hour will be in excess of 200 million dollars per year. This water would be transferred to the watersheds of rivers that flow into the Yangtze, downstream of the Three Gorge Dam, so all of it would be lost to power generation. If water is not transferred to another watershed, at least some may be collected from irrigation operations and returned to a reservoir.

TABLE XIV

UNIT IRRIGATION ENERGY REQUIREMENTS

Irrigation Method	Method Efficiency (percent)*	Energy required to deliver one hectare-meter of water		
		Surface Water	Groundwater	
			50 m lift	100 m lift
Surface	50	292 kWh	3,850 kWh	7,400 kWh
Surface	70	231 kWh	2,780 kWh	5,330 kWh
Surface, with runoff recovery	85	338 kWh	2,450 kWh	4,550 kWh
Hand-moved sprinklers	75	2,590 kWh	4,980 kWh	7,350 kWh
Trickle	90	1,700 kWh	3,700 kWh	5,680 kWh

* 'Method efficiency' is defined as the amount of water brought to the farm irrigation system minus water losses enroute, specified as a percentage.
References: Gloyna and Goldsmith.

Waterborne Diseases. Irrigation projects may create conditions favorable for the breeding of waterborne parasites and the diseases they carry, resulting in significant loss or shortening of life.

In order to measure the impact a project will have on the incidence of waterborne diseases, it is necessary to study in detail the proposed project in light of similar projects that have been constructed in areas which possess similar insect breeding conditions. If the results of such analysis show that waterborne diseases may spread, vigorous steps must be undertaken to insure that carriers never have a chance to gain a foothold.

The Jiangsu Institute for Research on the Prevention and Cure of Schistosomiasis states that carrier snails do not usually thrive north of a latitude of $33^\circ15'$ North, so the potential for the transfer or transmission of this disease will be negligible in the case of the Three Gorge Reservoir.

The Role of Three Gorge Dam in Large-Scale South-North Water Transfer.

Introduction. Currently, no irrigation waters are expected to be drawn directly from the Three Gorge Reservoir. The primary irrigation benefits of the project will be indirect, and will occur more than a thousand kilometers downstream of the dam.

North China supports 51 percent of the nations's cultivated land, but possesses only seven percent of the country's total surface water flow. The figures for the Yangtze basin and southern China are 33 percent and 76 percent, respectively (Howe, Christopher). Because of this regional disparity between water resources and arable land, the Chinese government has been studying the feasibility of transferring large amounts of water from the wet Southern regions to the dryer Huai and Hai Plains and northern coastal regions. Three general water transfer routes have been studied, and, over the years, the Eastern route has emerged as the most feasible, both physically and financially (Kao).

Any of the proposed Three Gorge Dam heights would provide a reliable source of water for the irrigation of China's already fertile North Plains. The transfer of large amounts of Yangtze River water would require the construction of a massive canal project of the same magnitude as the largest in the Western United States. This sort of

project would have national consequences, and would require a detailed benefit-cost analysis of the same detail as that required of the Three Gorge Dam.

The primary benefits of such a transfer would be the supplemental irrigation of 4.3 million hectares of land, improved navigation on the reconstructed Grand Canal, and municipal and industrial water supply for the city of Tianjin (Postel). The total annual amount of water pumped would range from 15 cubic kilometers in a normal water year to 30 cubic kilometers in a dry year (475 to 950 cubic meters per second). The anticipated cost of the project would be at least $5.7 billion.

In February of 1983, the Chinese government approved the first stage of work on this alternative, which primarily consists of a reconstruction of the Grand Canal (Postel). The Grand Canal, begun in about 400 BC, links Beijing and Hangchow. Water will be withdrawn from the Yangtze River in the vicinity of Yangshou and Jiangdu in Jiangsu Province. It will be pumped 660 kilometers north, siphoned under the Yellow River in large-diameter tunnels to avoid mixing with its silt-laden waters, and will then flow 490 kilometers by gravity to the vicinity of Tianjin. The water will be regulated by the storage capacity of four large freshwater lakes: Hongze, Luoma, Nansi and Dongping. The total area of these lakes, which range in depth from two to four meters, is about 380,000 hectares (Biswas, 1983).

The total lift over the first stage will be 65 meters, requiring a total pump station installed capacity of about 1,000 megawatts.

Depending upon the amount of water taken from the Yangtze, annual energy consumed will range from three to five terawatt-hours.

This soonest that this irrigation project could be built would be after the turn of the century. Due to the near-total uncertainty regarding all project consequences, the United States Three Gorge Working Group and others have recommended that upstream irrigation benefits due to the Three Gorge project not be quantified at this time. Additional Three Gorge Project Irrigation Benefits.

The indirect irrigation benefits that will accrue to the Three Gorge project are not limited to those that may be reaped by a water transfer scheme that may not be constructed for many decades. The presence of the reservoir will allow annual low flows to be augmented, thereby cutting down on saline intrusion into the Yangtze delta and leading to an increase in crop production, although this benefit has not yet been quantified by the Chinese government.

The Yangtze River flows through two main channels before it discharges into the East China Sea. The South branch, which is the navigation channel, takes about ninety percent of the river's flow. The North branch provides a westward-flowing channel for intruding salt water. This intrusion is most serious during the Yangtze low-flow season from December to April. Over the last ten years, data at Laoshidong (upstream of Wusong) show a maximum salt concentration of 2,460 parts per million (ppm), far above the 1,100 ppm limit required for general irrigation.

In 1978, the Yangtze experienced its lowest annual average flow in half a century. At one point, saltwater intruded 120 kilometers

upstream, and Chongming island lost 1,300 mou of rice, valued at about $25 million. The direct losses to industry exceeded $7 million (Biswas, 1983).

There is generally no salt intrusion into the river as far Wast as Datong when Yangtze River flow exceeds 16,000 cubic meters per second. Three Gorge Dam will be capable of maintaining minimum flows at this level, although an analysis which evaluates tradeoffs between project purposes has yet to be performed by the Chinese government.

CHAPTER IV

METHODOLOGY: EVALUATION OF THREE GORGE PROJECT NET ECONOMIC BENEFITS

INTRODUCTION

This chapter outlines the evaluation of the Three Gorge Dam and Reservoir from a purely economic perspective by assessing the tangible economic net benefits of the project: flood control, hydropower, navigation, irrigation, and recreation benefits, and construction and operation costs.

The environmental and sociological perspectives, to the extent that they incur tangible benefits and costs, are also addressed in this chapter. However, since the emphasis of these latter two perspectives primarily is upon intangible effects, they are evaluated in Chapter V.

Detailed background information on the areas to be affected by each Three Gorge project function is provided in Chapter III. Each section below briefly speaks in general terms about the evaluation of each project purpose, and then outlines the technical procedure for evaluating each. The detailed calculations have been removed to a separate reference (Clowes, 1987c), and are available for examination upon request.

The final product of this economic study is a relationship between the Three Gorge top of dam elevation, reservoir configuration, and annualized project net benefits, which is shown in Table XXIX at the

end of this chapter. This table is the first of the three indicators that will be used to select the range of Three Gorge project alternatives that maximize total economic, sociologic, and environmental welfare over time.

EVALUATION OF THREE GORGE PROJECT NET FLOOD CONTROL BENEFITS

General Principles.

Despite the constant threat of disastrous flooding, man has habitually located many of his major cities in floodplains or near rivers so that he may have ready access to an ample supply of water for drinking, cleaning, and irrigation. Floodplain fertility and flatness encourages urban, industrial, and agricultural development. Additionally, rivers have always served as important transportation arteries.

As cities grow, flood protection typically evolves from form to form. Initially, the most economically and physically feasible option might be to floodproof individual structures. As small villages grow into towns, economy of scale dictates that levees can better protect a large area for the lowest cost. Finally, as long river reaches become heavily urbanized, large flood detention reservoirs are built individually or in series to help prevent flooding in conjunction with the levee systems.

Purpose of this Study.

This section describes a procedure for determining the optimum elevation for the Three Gorge top of dam and the corresponding most favorable bottom of conservation pool elevation so that project net tangible flood control benefits may be maximized.

This study, of course, explores the benefits and costs of project flood control operations in isolation. However, the Chinese government has frequently stressed that flood control is the primary purpose for which Three Gorge Dam is being constructed, and that all other purposes, including hydropower, navigation, and irrigation, must be optimized with respect to flood control operations. Therefore, this section of the study shall take this constraint into consideration by attempting to optimize the Three Gorge Dam and Reservoir for flood control operations only. Subsequent sections of this chapter contain studies of other major project benefits and costs with the understanding that the project configuration for flood control may be altered with respect to top-of-dam elevation or reservoir operating rule curves.

The Net Benefit Evaluation Procedure.

Introduction. The general procedure for assessing damages caused by flooding is extremely data-intensive and complicated, particularly when assumptions must account for gaps in available information. This is certainly the case with the Three Gorge Dam and Reservoir. Although hydrologic and population data is plentiful and reliable, information on indirect damages and future basin development is almost impossible for foreign engineers to obtain. Table XV outlines a proposed procedure for assessing net flood control benefits, and the following sections describe this procedure in more detail.

The calculations that support the conclusions of this section may be performed with a hand calculator or basic spreadsheet program in a relatively short period of time by a qualified economist or engineer.

TABLE XV

OUTLINE OF METHODOLOGY:
EVALUATION OF TANGIBLE NET FLOOD CONTROL BENEFITS

(1) Define net flood control benefits.
    define direct flood control benefits, direct flood control
        costs, and indirect flood control costs

(2) Gather necessary information.
    hydrologic data: tailwater curves; downstream channel
        capacity; flood volumes and frequencies; elevation-area-
        capacity relationships; annual peak flows
    demographic data: populations of cities and rural areas;
        occupations and incomes of people affected; sociological
        data (ages, ethnic background, religions, relationships
        to other individuals and groups)
    damage data
        direct: farmland and crops; businesses; utilities; homes
            and contents; transportation systems
        indirect: lost production, earnings, and profit; costs
            of flood fights and evacuation; victim rehabilitation;
            increased travel time and expense
        intangible: loss of life; incurred disease ·incidence;
            lack of food and sanitation

(3) Determine range of alternatives to be studied.
    magnitude and distribution of the standard project flood
    magnitude and distribution of the project design flood
    spillway capacity and configuration
    project annual operating rule curve
    project configurations: elevations of top of dam, top of
        flood control pool, top and bottom of conservation pool

(4) Determine upstream permanent relocations costs.
    land permanently inundated
    permanent relocations of urban and rural dwellers
    assets: businesses, utilities, housing and contents
    engineering, design, supervision and administration
        (ED&SA), and interest during construction (IDC)
    other project benefits foregone due to flood control
        operations

(5) Determine total temporary relocations costs.
    hand-route floods of various return periods through the
    project in order to determine the amount and cost of
    upstream and downstream temporary relocations and inundated
    farmland.

(6) Calculate net present-worthed project flood control benefits.

The following procedure reduces the infinite universe of possible project configurations to a manageable range, and is particularly appropriate to the situation in a developing country, where a study team may have the necessary expertise to perform a study, but have no available computer hardware or software.

Step 1: Define Net Flood Control Benefits.

It is generally quite difficult to entirely segregate the flood control benefits of a project from the permanent and temporary relocations required to make it operational. Although a large reservoir will receive a large portion of its benefits from preventing temporary relocations and inundation of farmland downstream, it will cause both permanent and temporary relocations and the permanent inundation of considerable tracts of farmland upstream.

Since the Three Gorge project has major multiple purposes, its construction costs are dealt with in a subsequent section of this chapter. In order to determine the economic feasibility of the flood control function of the Three Gorge Dam and Reservoir, a standard cost allocation by the separable costs-remaining benefits (SCRB) method should be performed. This procedure, which is outlined in Appendix C, is complex and beyond the scope of this dissertation. However, even without an SCRB cost allocation, this study will yield a definite indication of Three Gorge project economic feasibility.

This section will clarify the discussion of net Three Gorge project flood control benefits by dividing them into three categories;
* direct flood control benefits, defined as downstream temporary relocations and inundated farmland prevented by project flood control operations,

* direct <u>flood</u> <u>control</u> costs, defined as upstream permanent <u>relocations</u> <u>and</u> inundated farmland caused by project construction, and

* <u>indirect</u> <u>flood</u> <u>control</u> <u>costs</u>, defined as upstream temporary <u>relocations</u> <u>and</u> <u>inundated</u> farmland caused by project flood control operations.

<u>Step</u> <u>2</u>: <u>Gather</u> <u>Pertinent</u> <u>Information</u>.

<u>Required</u> <u>Hydrologic</u> <u>Information</u>. Hydrologic and damage data which has been assembled over an extended period of record will usually be available in areas where the construction of a large reservoir has been contemplated for an extended period of time. This is certainly the case regarding the Three Gorge Dam and Reservoir at Sandouping. Accurate river stages dating from the year 1153 are available for examination, allowing a great degree of confidence in any calculations based upon this data. The primary source of basic hydrologic data (tailwater curves, channel capacities, and flood volumes, peak flows, and recurrence intervals) is the Ministry of Water Resources and Electric Power, as specified in Volume 2, "Hydrology," and Appendix 3, "Attached Maps," of their 1983 Feasibility Study Report. This data is reliable and consistent, and has served as the basis for numerous studies in China (MWREP, 1983b).

One of the most basic items of information required in this study is the elevation-area-capacity relationship of the proposed Three Gorge Reservoir. This information is used to calculate the flood storage capacity of the reservoir and the required upstream temporary relocations and inundated farmland. It also serves as a basis to prorate certain costs with regard to a fixed figure, such as utilities

relocations costs for various reservoir maximum normal water surface elevations.

Required Demographic Data. In order to obtain accurate relocations costs, this study must use the basic characteristics of the urban and rural population in the vicinity of the proposed Three Gorge Reservoir that is likely to be affected by both reservoir filling and reservoir flood control operations. This information should include the total number of city and village dwellers and the range of elevations of each population center. Due to the absence of detailed elevation data, it is assumed that the population in each city and village, and the residual population dwelling in remote areas, is uniformly distributed by elevation. Supplemental information of interest would show how each of the population centers specified above have been affected by historical floods. The extraordinarily large range of Yangtze River surface elevations have been a bane to navigation throughout the centuries. For example, the historical river elevation fluctuation at Fengjie and Yunyang has been about 72 meters (235 feet), and elevation changes within a five-day period can be fifty meters or more.

Required Potential Damage Data. Unfortunately, damage information is much less reliable and available than either hydrologic or demographic information. The Yangtze floodplain is basically an area used for intensive farming and has not changed extensively in this regard for hundreds of years. However, a system of levees extending more than thirty thousand linear kilometers has been constructed in the last century, rendering previous structural damage estimates meaning-

less. The degree of potential serious structural damage has decreased drastically over the past fifty years due to the construction of this levee system to the point that almost all damage is inflicted upon small towns and farmland.

This study will assume that all significant downstream relocations occur among the rural population and further, that all significant damages occur to farmland and the homes and facilities of rural dwellers. This may not strictly be the case, because a very large flood event of 10,000 year or greater return period may indeed cause great damage to cities such as Wuhan, despite the use of the extensive levee system and flood diversion areas. However, annualized costs due to downstream urban damages and relocations would probably be insignificant relative to rural damages when the vast levee system and flood diversion areas, which did not exist fifty years ago, are taken into consideration.

Damage Classifications.

General. Flood damages are usually divided into direct, indirect, and intangible categories, as described below. Direct and indirect damages must be quantified in common units, and the total damage figure must be updated to current-year values and adjusted for development that has occurred since that year. Intangible damages, including loss of life, may also be assigned common units. However, any such designation must be completely arbitrary. Intangibles, especially loss of life, should stand on their own merits as additional measures of project worth.

Direct Damages. Direct damages are defined as the actual costs that would be incurred to replace facilities, goods, and other physical objects that have been destroyed by a flood event. This category includes damages to structures and their contents, highways, railroads, bridges, and utilities. Damage is appraised in terms of actual replacement or repair costs, regardless of whether such work is performed or not (Howe; Kuiper).

Direct damages also include agricultural crop losses, which are appraised in terms of their market value, less costs not yet incurred at the time of loss. Flood damages to crops are estimated by examining farm budgets. Unit prices for each category of crop are developed from the labor and material costs paid by each individual farmer to grow them. An estimated average crop yield per acre is derived, based on local average soil and weather conditions with no flooding. Direct agricultural damages include crops destroyed, livestock killed, the cost of replacement or repair for damaged or destroyed equipment, and the costs of cleanup, clearing, releveling, replanting, and extra fertilizer to replace that which is washed away (James).

Direct damages have been set at $14,300 per hectare for lands in the fertile middle Yangtze floodplain (MWREP, 1983b; USBR, 1984; C3GPDC). This high figure reflects the Chinese government's assessment of the actual value of crops lost to floodwaters and the immense amount of work required in preparing the land for replanting.

Indirect Damages. Indirect damages are those secondary or tertiary damages that occur to entities such as individuals, businesses, and utilities. They include losses of income due to the

interruption of business, appraised in terms of goods or services not produced due to the flood, and the cost of flood fights, evacuation, and the care and rehabilitation of flood victims (NHRI).

Also included are increased costs of travel, defined as the actual cost of travel during flood events minus the cost of travel along normal routes. Losses due to flood-induced interruptions in utility services will also occur.

On a more abstract level, the net loss of normal profit and earnings to capital, management, and labor in the flood zone must be accounted for, in spite of the fact that it is very difficult to do so (Kuiper). From a national accounting stance, business losses inside the floodplain will tend to be offset by business gains outside the floodplain, so indirect losses are much lower from a national viewpoint than from a local standpoint (McKean).

Indirect damages are extremely difficult to quantify for a large number of flood events, and so are usually taken as a fixed percentage of direct damages. Kayes, after studying a number of Corps of Engineers analyses, derived average values for the United States (Howe, Charles). These values include a ten percent adjustment for agricultural direct damages. As an example of how the direct/indirect damage ratio may vary from country to country or from region to region, the Chinese government has stressed the great importance of the land to the people by setting indirect damages fully equal to direct damages for inundated farmland (USBR, 1984; C3GPDC). This value includes most indirect damages to the very few major roads, railroads, and utilities

that exist within the vast floodwater diversion areas, which are primarily agricultural in nature.

The remaining major indirect damages suffered in Yangtze floods include lost wages and the cost of flood fights and evacuation, as well as the costs of temporary shelter for the displaced peasants. The derivations of these additional indirect damages are included in the temporary individual relocations costs quoted by the Chinese government (Clowes, 1987c).

Intangible Damages. These damages are difficult to quantify, and are sometimes estimated as the costs of providing alternative but equal services to replace such services lost due to a flood event. Other intangible damages, such as loss of life, can only be accounted for by assigning an arbitrary value (Liu).

The decisionmaker must assign his own values to these intangibles. If the analyst performs this task, he is, in essence, partially or wholly deciding the outcome of project selection rather than the decisionmaker. For the purposes of this study, the estimated annual number of lives saved by the construction of various Three Gorge alternative projects is kept separate from other criteria until the final stages of the project selection process.

Intangible damages include public health dangers due to contamination of water supplies, the spread of disease and insects, and lack of proper food and sanitation. Also included in this category are adverse effects on national defense by the closure of major transportation and communications arteries.

Perhaps the most important intangible cost is the damage that can be caused by a false sense of security that becomes ingrained when the population downstream from a dam perceives that the project can eliminate all flooding. There is a very real danger that a greater-than project design flood will someday occur under an extraordinary set of meteorological and physical circumstances. In this case, far greater damage may result than if the project was never built at all, because greater floodplain development will occur with the dam than without it. The Corps of Engineers uses a very high PDF because;

> If the degree of protection originally provided is too low, a false sense of security is induced, unwarranted development is encouraged, and when the great flood comes, inevitably the stage will be set for a disaster.
> (Howe, Christopher)

The quantification of intangible flood damages is a most intractible problem in China. However, the character and usage of the affected floodplain, and, indirectly, China's formidable and effective family planning program, simplify matters considerably.

A subsequent portion of this section includes calculations that correct for minor population increases in the rural areas that would receive flood control benefits from the Three Gorge Dam and Reservoir. In China, perhaps more than in any other country, this population increase can be accurately foretold, due to the emphasis the central government places upon controlling its population. Although the edicts of this policy are not observed as strictly in the country as in the cities, relatively accurate population growth rates are still available for use. The basic assumption that the land in the flood diversion

areas will remain under cultivation is also logical in light of the well-organized land use pattern in this area. The middle Yangtze floodplain is protected by the most complex floodwater diversion scheme on earth, and the Chinese are fully aware that uncontrolled urban or industrial development here will not only consume scarce farmland, but may also prove disastrous if a truly exceptional flood event ever occurred, even in the presence of the Three Gorge Dam.

Step 3: Determine the Range of Alternatives to be Studied.

Three Gorge Project Mode of Operation. The primary objective of Three Gorge Dam flood control operations, as stated by the MWREP, is the protection of the heavily-cultivated and densely-populated flood diversion areas downstream of Yichang and the major population center at Wuhan (MWREP, 1983a and 1983b; USBR, 1984; Moyes, 1986).

Figure 4 depicts the Three Gorge Reservoir rule curve as specified in the MWREP's Feasibility Study and modified in subsequent communications. Critical data are as follows; .

* top of dam elevation: 175 meters
* top of flood control pool elevation: 174 meters
* top of conservation pool elevation: 160 meters
* bottom of conservation pool elevation: 135 meters
* total flood control storage space (between elevations 135 meters to 174 meters): 25.8 cubic kilometers (20.9 million acre-feet)
* storage from streambed to 160 meters: 26.2 cubic kilometers (21.2 million acre-feet)

The pool begins the calendar year at 160 meters elevation, and is drawn down steadily during the first quarter until it reaches an elevation of 135 meters on March 31st. The pool remains at this level for flood control purposes until the first of October. It is refilled
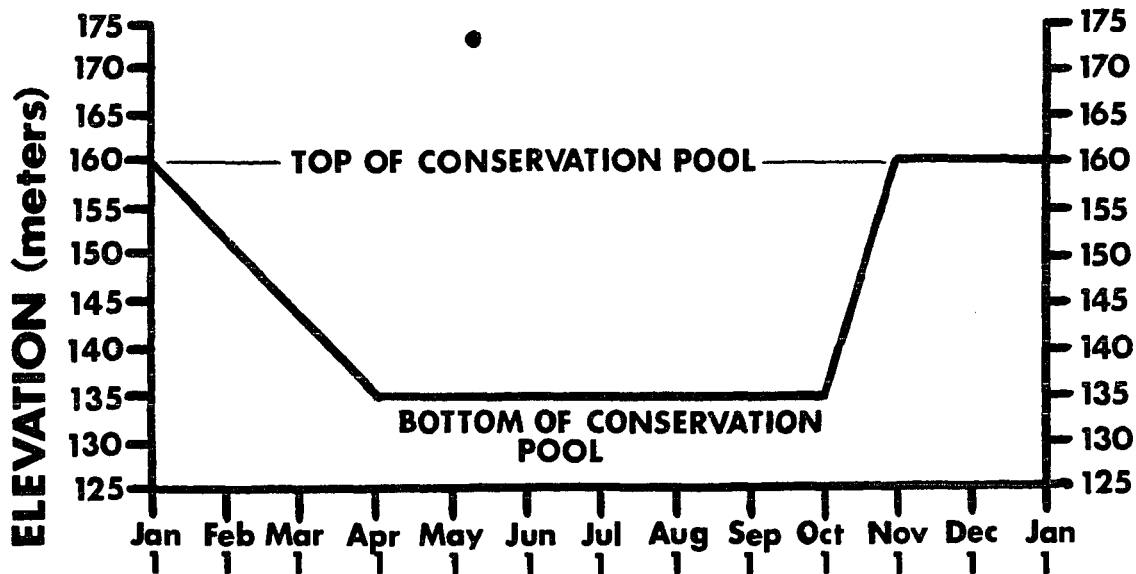
Figure 4. Three Gorge reservoir rule curve (approved project
configuration).

to the top of conservation pool elevation by the first of November, and
remains at that elevation until the end of the year.

Sizing a Flood Control Reservoir. A single-purpose or multiple-
purpose flood control project that is optimally sized for the project
design flood (PDF) will have evacuated its flood control storage
completely at the beginning of the event, and will be sized such that
its flood control storage space will exactly equal the volume of the
PDF minus the volume of water passed downstream at bankfull capacity
during the flood. The project will, throughout the flood event,

release flows equal to the downstream channel capacity less local inflow between the dam and the downstream floodplain. At the end of the flood event, the project will evacuate the flood control storage as rapidly as possible without causing downstream flooding.

Of course, no flood control reservoir ever constructed has been precisely sized for the greatest economic efficiency. In fact, most existing flood control dams have never been tested to anywhere near their capacity by the floods that they have experienced. However, the idea is to guard against saving a relatively small amount of construction money while risking untold damage downstream by underdesigning a dam and reservoir for flood control purposes. Most domestic and foreign governments and agencies of good reputation specify very high standards with regard to flood storage space and spillway capacity.

The Standard Project Flood (SPF). In the United States, the Army Corps of Engineers retains primary responsibility for flood control at all major multiple-purpose reservoirs. The Corps generally uses the standard project flood to size its reservoirs and spillways. The SPF is based on "the most severe combination of meteorological and hydrological conditions that are considered reasonably characteristic of the geographic region involved, excluding extraordinarily rare combinations." The SPF value generally exceeds the value of the flood of record (Corps, 1981). In more than five thousand project-years of operation, no Corps of Engineers project has ever exceeded its spillway capacity. This suggests that the SPF may not be the most economical choice for the PDF.

A flood control project that will accrue maximum net benefits will almost certainly be designed to contain a PDF that is considerable smaller than the SPF. This is due to the fact that SPF's, although devastating, have an extremely low probability of occurrence in any given year and therefore, a relatively low annualized damage figure.

Routing the Three Gorge Project Flood of Record. The Ministry of Water Resources and Electric Power (MWREP) retains responsibility for properly sizing the reservoirs and spillways of large multiple-purpose Chinese dams. After extensive consultation with the Corps of Engineers, the Bureau of Reclamation, and other agencies, the MWREP designed the Three Gorge Dam to pass the peak flow of the standard project flood for the Sandouping damsite through its bottom outlets, spillway sections, diversion channels, and turbines.

After review of the Yangtze's extraordinary 1,000 year hydrologic period of record, the MWREP set the SPF peak flow equal to ten percent greater than the estimated 10,000 year flood, or about 128,500 cubic meters per second (4,237,000 cubic feet per second). This enormous flood would produce an average one-day flow of about 128,000 cubic meters per second (CMS), an average seven-day flow of 120,000 CMS, an average fifteen-day flow of 105,000 CMS, and an average flow over one month of about 88,500 CMS. Such an extraordinary flood would far exceed the volume-based parameters of any other Yangtze River flood on record, and would have to combine unusual antecedent soil moisture conditions with a storm or storms of truly exceptional scope. However, the very fact that the MWREP has assigned such a value shows that senior Chinese water resources planners are generally in agreement that

such an event is within the realm of possibility. It is their opinion that underdesigning a reservoir or spillway to deal with the standard project flood could be disastrous.

The 483 meter long Three Gorge Dam spillway will consist of twenty-two 21 meter wide by 8 meter deep sections. Additionally, the project will be equipped with 23 bottom outlets of dimensions 7 by 9 meters, and 22 diversion sluiceways of dimensions 5.5 by 20 meters (Harza). During major flood events, a total flow of about 20,000 cubic meters per second may also be passed through the project's turbines, assuming that six of these units are down for repairs (Clowes, 1987c).

At the beginning of the 1954 magnitude flood event (considered to be the flood of record), it is assumed that the reservoir is at the bottom of its conservation pool elevation. This assumption is considered reasonable in light of the fact that each of the ten largest floods of record, and every annual peak flow of the last century, has taken place between May 15 and October 5. In fact, all but three of these annual peak flows occurred in the months of July, August, and September (Rodier). Since the magnitude of the flood will probably not be known for several days, the dam will release water at a rate equal to reservoir inflow until this inflow equals or exceeds the downstream channel capacity of 56,700 CMS (about 2,000,000 CFS). This event occurs on approximately day six of the flood event (Clowes, 1987c).

At this point, the reservoir will now begin to store excess floodwater. By day eleven, the reservoir has risen to an elevation of 160 meters, which is the top of its conservation pool, and proceeds to fill into its flood control storage space. As the reservoir elevation

rises 14 meters to the top of the flood control pool, extensive upstream temporary relocations will result. No downstream temporary relocations will take place until the dam begins flood releases in excess of 56,700 CMS.

By day thirteen, the water has reached the top of the flood control pool at 174 meters, and total dam discharge through spillways sections, turbines, bottom outlets, and diversion sluiceways will be held equal to reservoir inflow. All excess water will be passed downstream without attenuation, and the six existing floodwater detention areas will be called into use in the sequence specified by the MWREP. Until the reservoir inflow falls below 56,700 CMS, downstream temporary relocations and farmland inundation will continue to mount (Clowes, 1987c).

The Flood of 1954 produces 24.8 cubic kilometers of floodwater in excess of the Three Gorge Reservoir flood storage space. This water will be impounded by the downstream flood diversion areas, causing great damage to crops and the dwellings of the rural peasants.

This assumed mode of reservoir operation will result in approximately the same amount of inundated farmland and temporary relocations that would result if flows larger than channel capacity were released earlier in the flood event, because the amount of excess floodwater will be the same regardless of the sequence in which it is released, and will be diverted into the Jinjiang floodwater storage areas in order to protect the heavily-urbanized areas further downstream. An advantage of this operating regime is that, in the event of a large flood, several days of warning may be provided to

those in the downstream floodwater diversion areas, leading to a large number of lives being saved.

Assuming that the return period of the Standard Project Flood was 20,000 years, and that the damage inflicted by such a flood would be about $150 billion, the average annual damage prevented by a project designed to control it would be about $7.5 million. This figure represents about three percent of current total annualized flood damages. The probability that this disastrous flood would occur at any time during the entire century-long lifetime of the Three Gorge Dam is about one-half of one percent (Clowes, 1987c).

Range of Alternatives. The alternatives to be examined in this study will cover the approximate range of those configurations studied in China over the past fifty years, as described in Chapter III. The top-of-dam elevations to be studied will range from 100 meters to 210 meters in ten-meter increments (higher top of dam elevations are considered infeasible in light of statements by the Chinese government regarding excessive relocations at Chongqing). For each of these alternatives, five elevations for the bottom of the conservation pool will be studied; 20 to 40 meters below the top of dam, in five meter increments. The top of conservation pool elevation will remain, in all cases, ten meters below the top-of-dam elevation. This arrangement yields a total of 59 alternatives, summarized in Table XVI.

A 'dry' single-purpose flood control dam is not considered practical, due to the resulting insurmountable navigation blockage and the huge losses in hydropower revenues that would result from such a scheme. In any case, such a structure would have to be built to a

TABLE XVI

THREE GORGE RESERVOIR FLOOD CONTROL CONFIGURATIONS

(all elevations in meters)

Top of Dam Elevations	Bottom of Conservation Pool Elevations				
100	80	75	70	66	——
110	90	85	80	75	70
120	100	95	90	85	80
130	110	105	100	95	90
140	120	115	110	105	100
150	130	125	120	115	110
160	140	135	130	125	120
170	150	145	140	135	130
180	160	155	150	145	140
190	170	165	160	155	150
200	180	175	170	165	160
210	190	185	180	175	170

height of 205 meters in order to contain the standard project flood, if the downstream channel capacity is not to be exceeded (Clowes, 1987c).

Step 4: Calculate Upstream Permanent Relocations Costs.

The Importance of a Good Permanent Relocations Estimate. The previous chapter outlined the technical and philosophical objections to Three Gorge Dam that have recurred repeatedly during its long and stormy planning history. These include doubts as to the country's ability to construct a project that is at the cutting edge of technology in so many areas. However, the primary objections concern the enormous number of persons that must be permanently relocated should the project be built. These relocations include not only the costs of relocating large segments of several cities, but, perhaps even more importantly, the permanent loss of critically short farmland. As Figure 3 in Chapter III showed, permanent farmland losses increase

steadily with a rise in the top of conservation pool elevation from 100 to 160 meters, and then increase at a greatly accelerated rate above an elevation of 160 meters.

Because relocations costs and farmland losses rise so sharply with reservoir area, it is essential they be quantified as precisely as possible before a top-of-dam height is selected.

Direct Flood Control Project Costs. The direct relocations costs of a flood control project fall into four general categories, as described in the following paragraphs.

(1) Land. The value of land that will be committed specifically to flood control structures and storage, to include flooding easements, can be quite significant. In the case of the middle Yangtze floodplain, these easements take the form of vast tracts of agricultural land that contain floodwaters during serious flood events for the protection of large urbanized areas downstream. These, however, are sunk costs, and the Three Gorge Reservoir, together with additional future flood storage, may eventually free these areas entirely from the threat of flooding.

Upstream land inundated permanently by the reservoir is accounted for in this chapter. The land in the area of the Three Gorges generally yields two crops per year at the rate of about 17 metric tons per hectare annually of rice, corn, wheat, and/or potatoes (MWREP, 1983b; USBR, 1984). The Chinese government has assigned an average value of $31,000 per hectare of farmland permanently lost to production due to reservoir inundation.

(2) Permanent Relocations of People. One of the critical factors in sizing the Three Gorge Dam and Reservoir is the direct and indirect costs of permanently relocating individuals upstream of the dam to make way for reservoir filling. The permanent relocation of individuals is classified as either rural and urban, due to the large difference in per capita costs between relocating an urban dweller and a rural dweller.

The number of individuals to be relocated in rural and urban areas is based upon original Chinese population data projected to a 1989 Three Gorge Dam construction start date. Rates of growth during the period 1984 to 1993 are 0.68 percent per year for villages, and 0.86 percent per year for cities. Since project construction is currently

scheduled to begin in 1989, and permanent relocations will begin in year 4 of project construction (1993), the total population update factor from 1989 to 1993 is 1.035 for villages and 1.044 for cities.

The costs of permanently relocating each urban and rural dweller are $1,415 and $255 respectively. The components of this cost are utilities (sewers, water, electricity, communications, transportation), personal belongings and furniture, moving costs, indirect losses (missed wages, etc.), a government "land expropriation compensation," and miscellaneous relocation costs (cultural resources preservation, reservoir clearing, and other utilities) (MWREP, 1983a and 1983b; USBR, 1984).

(3) Asset Relocations.

* Housing Relocations. The Ministry of Water Resources and Electric Power has provided a living quarters and public buildings allowance of $1,547 for an urban dweller and $877 for a rural dweller. This allowance is based upon living spaces of 10 square meters and 15 square meters per person, respectively.

* Fixed Asset Relocations. No detailed plant-by plant inventory and assessment of fixed asset relocations costs has yet been performed for factories and businesses. Therefore, the Chinese government has estimated the relocation cost of industry by summing its components; (1) the costs of rebuilding each production facility, (2) a "land expropriation fee" equivalent to $29,700 per million dollars of existing fixed assets, and (3) a down-time wage subsidy. This subsidy assumes 91 workers per million dollars of fixed assets, and an average downtime of one year at a rate of $70 per month per worker, yielding a total down-time wage subsidy of $76,500 per million dollars of fixed assets (C3GPDC). The resulting value is prorated per the total urban population to be relocated (Clowes, 1987c).

* Utility Relocations. The MWREP has provided quantities and unit prices for the relocation of utilities at the 150 meter normal water surface elevation. These unit values are prorated per the Three Gorge Reservoir elevation-area relationship for higher and lower normal water surface elevations (Clowes, 1987c).

The base figure for utility relocations costs at the 150 meter normal water surface elevation are $18 million for 172 kilometers of highway, and $11 million for 729 kilometers of telecommunications circuits. The total utility relocations cost is therefore $29 million.

(4) **ED&SA** and **IDC.** A 15 percent allowance for administration,
design, supervision and administration (ED&SA) is quoted by
the Ministry of Water Resources and Electric Power (MWREP,
1983b). The project interest during construction (IDC) for
permanent relocations was calculated for four different
interest rates (3, 5, 7, and 9 percent).

Upstream permanent relocations are assumed to follow
the same schedule as specified by the Ministry of Water
Resources and Electric Power in their 1983 Feasibility
Report. However, this time schedule was altered to reflect
an updated earliest possible project construction start
date of 1989. All populations are updated by the
applicable city or town growth rate stated earlier. For
example, the assumed schedule for the 180 meter normal
water surface elevation would be as follows;

* relocate from the 4th to 6th years of project construction
  (1993 to 1995) all persons below an elevation of 50 meters
  below the top of conservation pool (130 meters - 26,680
  persons),

* relocate from the 7th to 9th years of project construction
  (1996 to 1999) all persons above 130 meters and below an
  elevation of 20 meters below the top of the conservation
  pool (160 meters - 422,880 persons), and

* relocate from the 10th to 12th years of construction
  (1999 to 2001) all persons above 160 meters and below the
  elevation of the top of the conservation pool (180 meters -
  149,225 persons).

IDC is calculated from the year that the relocations were
actually performed to the year 2001, when the Three Gorge
Reservoir will begin impounding water for flood control
purposes.

Since the amounts of farmland and buildings inundated
are very closely related to the number of individuals to be
relocated, IDC for these costs are prorated per the total
urban and rural population. However, the costs for
relocating factories and utilities are assumed to be evenly
distributed throughout the relocations period (construction
years 4 through 12), and IDC for these costs is calculated
accordingly.

Step 5. Calculate Net Temporary Relocations Costs.

Definitions. Temporary relocations may be counted as either a
benefit or a cost when associated with a flood control project,

depending upon whether they are upstream or downstream of the project.
If a flood control project prevents temporary relocations downstream as
a result of impounding floodwaters, the avoided costs of relocation may
be counted as a benefit. However, temporary relocations caused by
rising reservoir levels during flood control operations must be
subtracted from these benefits in order to yield a net figure of annual
average temporary relocations prevented.

Therefore, for the purposes of this study, net temporary
relocations are defined as total flood control benefits (downstream
required temporary relocations saved), minus upstream temporary
relocations caused by large fluctuations in the reservoir surface
elevation resulting from flood control operations.

Flood Control Benefits. Reservoir flood control protection covers
large areas and therefore cannot be provided only to those individuals
and entities who desire it. Flood control benefits cannot be estimated
by examining market demand because it is a collective, rather than a
market good. Flood control benefits are estimated indirectly by
assuming that the group of all entities protected would be willing to
pay an annual amount for flood protection equal to annualized losses
incurred in the absence of the project. Therefore, demand for flood
control is set equal to the difference between expected flood damages
before and after the project is built.

The benefits that accrue to a flood control project fall into
three general categories;

    (1)   the damage prevented to all present and future floodplain
           property that would exist in the absence of the project.
           One of the primary assumptions of this study is that the

use of the middle Yangtze floodplain will remain primarily agricultural, in response to strict population and land use controls. Therefore, the vast majority of all damage prevented in this area will result from avoided crop damage and temporary relocations costs. Large floods with long return periods may occasionally cause heavy damages to urban areas that are protected by levees. However, when the expected value of the damages wrought by these large floods are present-worthed and annualized, they become insignificant when compared to more common rural and agricultural damages, especially at today's higher interest rates. For this reason, urban flood damages are disregarded in this study.

(2) the damage reduction beyond the entity's willingness to pay for development that could not economically have located in the floodplain without the project. Another way of describing this benefit is to quantify the exact level of damage reduction required to lure entities into the floodplain. No benefits should be counted for those businesses lured into the floodplain by a false sense of security stemming from overconfidence in a project's effectiveness (Howe, Christopher). This benefit is assigned a value of zero for all Three Gorge project configurations, in light of the fact that the existing flood diversion plains, which occupy most of the area under study, are periodically inundated. This would render heavy development for industry economically infeasible. It is possible, however, that the Three Gorge Dam may be constructed to such a height (190-200 meters) that it will be capable of containing or greatly attenuating the standard project flood. Alternatively, the dam may be built to a lower height in conjunction with upstream flood storage. In either case, large flood diversion areas might thus be opened for urban or industrial development. This possibility should be investigated in more detail by the Chinese government.

(3) the enhanced productivity of the floodplain in terms of increased net income from new activities that replace old activities (i.e., new agriculture replacing old pasture), or new business and industry that locates in the floodplain because it is profitable only in the presence of the new dam (Eckstein). In the central Yangtze floodplain, such activities include the production and processing of sugar cane, herbs, cotton, grain, and vegetable oil (Bonavia, Judy). Light industries include brickmaking, fisheries, and forestry operations. The Three Gorge Dam and Reservoir might allow some of the several existing large flood diversion areas to be permanently flood-free, thus opening them for urban and industrial development.

The Value of Inundated Farmland. The land downstream of the proposed Three Gorge Dam and Reservoir is heavily populated and very heavily cultivated. In fact, it is known as the 'breadbasket of China.' A 1980 study showed that the direct damages caused by the temporary inundation of one hectare of prime farmland would be $14,300 (MWREP, 1983b). This figure was confirmed by a 1984 field study in the Danjiangkou area (USBR, 1984). Indirect agricultural damages are approximately equal to direct damages, resulting in agricultural damages of $28,600 for each hectare of farmland that is temporarily flooded (C3GPDC).

In order to determine the amount of farmland that will be inundated by floods of varying volume, several assumptions regarding basin configuration must be established;

* the objective of Three Gorge Dam will be as stated earlier in this section: to maintain Yangtze River flow at Yichang at or below the existing channel capacity of 56,700 cubic meters per second. The project will operate in the manner specified previously.

* when the Three Gorge project is completed, no large upstream storage projects will have been constructed.

* each flood storage area will be progressively flooded to a depth of three meters, at which point all persons will have been evacuated, and all farmland is considered inundated. It is assumed that all temporary relocations and agricultural and property damage will occur at a flood depth of three meters. After the flood storage area is flooded to a depth of three meters, it will then fill to its maximum capacity. The next flood storage area in the sequence will then be flooded. In rare cases (the 1,000 and 10,000 year floods), most designated flood storage areas will be flooded.

* The average damage incurred by the temporary inundation of one hectare of productive farmland is assumed to be $28,600 (MWREP, 1983b; USBR, 1984). The average cost of temporarily relocating one resident from a flood storage area is assumed

to be $1,240 for an urban resident and $600 for a rural resident, derived as follows (MWREP, 1983b; C3GPDC);

	Urban	Rural
45% damage to a single-story dwelling . .	$400	$360
45% damage to allocated public buildings .	300	45
35% damage to building contents	500	175
Indirect costs (including missed wages) .	40	20
Total temporary relocations cost -	$1,240	$600

Other flood factors, such as water velocity, temperature, entrained debris and pollutants, and total time of inundation, will affect damages as well.

Farmland Loss. Until this point, the Chinese government seems not to have performed detailed calculations which account for crops saved by various configurations of the Three Gorge Dam and Reservoir. The only figures available deal with areas of farmland permanently lost to cultivation. Although these figures account for most of the project's flood control costs, they are somewhat attenuated by the equivalent crops saved by reservoir flood control operations.

For the purposes of this study, It is assumed that all farmland, including that which is permanently inundated, produces (or produced) two uniform crops per year (MWREP, 1983b; USBR, 1984; Moyes, 1986). It

is also assumed that land which is temporarily flooded will lose one crop. Therefore, one hectare of land permanently flooded would be offset by two hectares of land protected from temporary flooding throughout the life of the project, strictly in terms of crop production.

Figure 3 of Chapter III shows that the lower dam elevations cause relatively little net crop loss. Due to the shape of the Three Gorges and the surrounding area, net crop loss increases quite rapidly for any dam height in excess of 160 meters. The incremental loss between 180 meters and 200 meters is quite significant. Therefore, the selection of any top of conservation pool elevation at or below 160 meters appears prudent.

The actual equivalent hectares of farmland lost to the project are shown in Table XVII. Equivalent farmland loss varies little with changes in bottom of conservation pool. This is due to the fact that floods with a volume large enough to exceed the top of conservation pool elevation (and therefore cause upstream temporary farmland inundation) are rare, so the annualized value of crops lost is relatively small.

Calculations. This section describes how temporary upstream and downstream relocations and agricultural damages are calculated.

Top-of-dam heights from 100 meters to 210 meters are examined in ten-meter increments. The maximum normal water surface elevation (also known as the top of the conservation pool) is initially set at an elevation of ten meters below the top-of-dam height. Each of the twelve top-of-dam elevations is examined with regard to four or five

TABLE XVII

EQUIVALENT PERMANENT FARMLAND LOSS FOR ALTERNATIVE DAM
HEIGHTS AND RESERVOIR MINIMUM NORMAL WATER SURFACE ELEVATIONS

Top of Dam Height (meters)	Actual Permanent Loss (hectares)	Bottom of Conservation Pool Elevations Relative to Top of Dam Height (meters);				
		-20	-25	-30	-35	-40
		Equivalent Permanent Loss (hectares)				
100	1,425	1,438	1,429	1,422	1,405	—
110	2,220	2,193	2,124	1,947	1,804	1,558
120	3,045	2,476	1,987	1,759	1,635	1,504
130	4,320	2,892	2,737	2,684	2,663	2,655
140	5,610	3,978	3,947	3,924	3,914	3,903
150	6,975	5,315	5,285	5,251	5,228	5,205
160	9,740	8,052	8,008	7,953	7,909	7,892
170	14,613	12,858	12,802	12,766	12,754	12,742
180	19,287	17,452	17,428	17,415	17,402	17,383
190	26,380	24,520	24,500	24,470	24,455	24,424
200	33,960	32,070	32,039	31,979	31,966	31,936
210	42,792	40,860	40,803	40,770	40,764	40,759

In all cases, the top of conservation pool elevation is ten meters below the top of dam elevation.

different bottom of conservation pool elevations corresponding to 20 meters, 25 meters, 30 meters, 35 meters, and 40 meters below the top of conservation pool. This range is examined in order to determine the impact of varied seasonal reservoir fluctuations on flood control and relocations costs and benefits.

Next, floods of various volumes and return periods are hand-routed through the Three Gorge Reservoir in order to determine the highest reservoir level that will be attained by each flood. If a flood fills the reservoir to within one foot of the top-of-dam elevation, excess flow beyond the downstream channel capacity of 56,700 cubic meters per second is directed into the flood storage areas as specified

previously. No upstream or downstream temporary relocations or agricultural damages occur during floods that produce a maximum reservoir surface elevation less than the top of the conservation pool.

If a flood results in a maximum reservoir elevation between the top of conservation pool and the top of the flood control pool, upstream temporary farmland inundation and relocations will result. These damages are tallied and added to the downstream damages previously calculated (Clowes, 1987c).

Step 6: Calculate Project Net Flood Control Benefits.

This final step merely combines the results of the two previous steps. The costs of the project (permanent and temporary upstream relocations), and the benefits of the project (downstream temporary relocations and inundated farmland prevented), are present-worthed, combined, and annualized over the life of the project at four different interest rates.

Figure 5 shows the annualized value of the total net flood control/relocations costs and benefits of the Three Gorge project over its design life of one hundred years. The calculation of each value in this set of curves was performed as follows:

(1) subtract annual upstream temporary relocations costs from the project downstream flood control benefits. Determine the value of this annual figure over the 100-year project life and present-worth it using interest rates of 3, 5, 7, and 9 percent.

(2) extract the appropriate upstream permanent relocations cost and present-worth it from 2001 using the above interest rates.

(3) subtract the result of step (2) from the result of step (1) and annualize it over the project life of 100 years using the above interest rates.

Summary of Economic Study: Flood Control Net Benefits.

Interest Rate Effects. The prevailing interest rate exerts a significant influence upon which range of project configurations will yield the greatest net flood control benefits.

Depending upon the final reservoir configuration, upstream Three Gorge permanent relocation costs will range from $29 million to $15,647 million, a variation of more than five hundred fold (Clowes, 1987c). At lower top of dam elevations (100 meters), these values for all interest rates exceed the present-worthed value of Three Gorge project lifetime flood control benefits (see Figure 5). Dam elevations of 100 meters and 200 to 210 meters actually show a negative annual net flood control benefit at all interest rates due to the drastically reduced present-worthed value of future flood control benefits.

The interest rate does not significantly effect the order of project configuration feasibility within and between dam heights. For all four interest rates (3, 5, 7, and 9 percent), plots of dam height vs. average annual benefits assume similar shapes, as shown in Figure 5. In all cases, the only dam heights that show a net positive flood control benefit for all bottom of conservation pool elevations are in the 120 to 150 meter range. Maximum annual flood control benefits for all interest rates are accrued by the 130 and 140 meter dam heights.

Table XVIII and Figure 5 show the result of this analysis. Higher dam heights will show large negative benefits due to the large present-worthed value of permanent relocations, which rises very rapidly above dam heights of 160 meters.

Flood control benefits in all cases increase slightly as the bottom of conservation pool elevation is dropped, due to an increase in available floodwater storage and a resultant decrease in downstream temporary relocatins. This study will therefore proceed with a bottom of conservation pool elevation which is twenty meters below the top-of-dam height, because it is expected that the incremental flood control benefits lost by such a move will be more than offset by hydropower benefits gained. This assumption will be cross-checked in the next section of this chapter.

Is the Approved Reservoir Configuration a Good Choice? It is logical that an increased reservoir flood storage capacity will lead to higher flood control benefits. If the top of conservation pool elevation is held constant, flood control storage space increases as the elevation of the bottom of the conservation pool drops, leading to larger annualized flood control benefits. It must be emphasized that this parameter deals with net flood control benefits only. As the winter drawdown increases, flood control benefits will increase as hydropower and navigation benefits decrease.

The flood control net benefit curves assume the characteristic shape shown in Figure 5 because permanent relocations for a particular top-of-dam height will remain the same, regardless of how far the pool is drawn down in the winter. Permanent relocations are dependent upon the maximum normal water surface elevation (the top of the conservation pool), which, for the purposes of this study, is assumed in all cases to be ten meters below the top-of-dam elevation. A more detailed study might consider several different top of conservation pool levels for
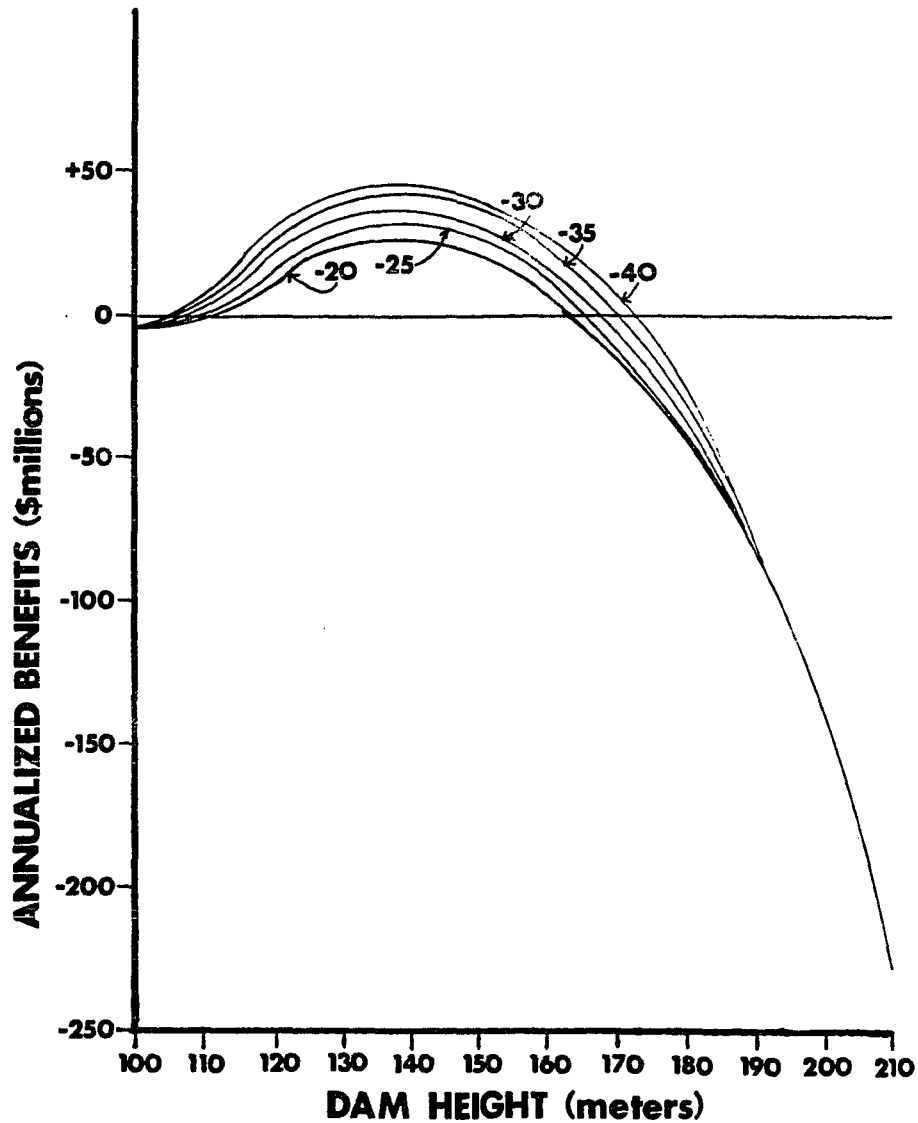
Figure 5. Annualized net lifetime Three Gorge project flood control benefits and relocations costs for alternative dam heights and reservoir minimum normal water surface elevations at seven percent interest. The negative numbers shown on the figure refer to the bottom of conservation pool elevation relative to the top of dam elevation.

TABLE XVIII

NET AVERAGE ANNUALIZED THREE GORGE PROJECT FLOOD CONTROL BENEFITS

(all benefits in $millions)

Top of Dam Height (meters)	Bottom of Conservation Pool Elevations Relative to Top of Dam Height (meters);				
	−20	−25	−30	−35	−40
Three Percent Interest					
100	−1.8	−1.5	−1.1	−0.5	——
110	−1.3	1.6	9.6	15.0	25.3
120	20.5	41.0	50.5	55.7	61.2
130	55.1	61.6	63.7	64.6	65.0
140	62.1	63.3	64.3	64.8	65.2
150	58.8	60.6	62.3	63.3	64.3
160	44.6	46.9	49.3	51.1	51.9
170	28.5	30.2	32.3	32.9	33.4
180	15.9	16.9	17.5	18.0	18.8
190	5.1	6.1	7.4	8.1	9.3
200	−45.7	−44.4	−41.9	−41.3	−39.6
210	−113.1	−110.6	−109.2	−108.9	−108.5
Five Percent Interest					
100	−2.1	−1.6	−1.5	−1.0	——
110	−2.1	0.2	5.8	10.4	18.3
120	14.1	29.8	37.0	41.0	45.2
130	39.8	44.8	46.4	47.1	47.4
140	44.5	45.4	46.2	46.5	46.9
150	40.1	41.4	42.7	43.5	44.2
160	21.6	23.4	25.2	26.6	27.2
170	−1.1	0.7	1.9	2.3	2.7
180	−19.4	−18.6	−18.2	−17.8	−17.2
190	−35.1	−34.4	−33.4	−32.9	−31.9
200	−100.4	−99.4	−97.4	−97.0	−96.0
210	−187.2	−185.4	−184.3	−184.1	−183.8

TABLE XVIII (continued)

NET AVERAGE ANNUALIZED THREE GORGE PROJECT FLOOD CONTROL BENEFITS

(all benefits in $millions)

Top of Dam Height (meters)	Bottom of Conservation Pool Elevations Relative to Top of Dam Height (meters);				
	-20	-25	-30	-35	-40
Seven Percent Interest					
100	-2.5	-1.8	-1.7	-1.3	——
110	-2.0	-0.9	3.2	6.5	12.1
120	8.6	19.8	25.0	27.9	30.9
130	26.4	29.9	31.1	31.6	31.8
140	29.0	29.7	30.2	30.5	30.7
150	23.9	24.9	25.9	26.4	26.9
160	3.2	4.5	5.8	6.8	7.2
170	-23.8	-22.5	-21.7	-21.4	-21.1
180	-45.9	-45.4	-45.0	-44.8	-44.3
190	-65.5	-65.0	-64.3	-63.9	-63.3
200	-138.8	-138.1	-136.7	-136.4	-135.7
210	-237.1	-235.8	-235.0	-234.9	-234.6
Nine Percent Interest					
100	-2.0	-1.8	-1.7	0.3	——
110	-1.7	-1.5	1.6	4.1	8.4
120	5.3	13.8	17.8	20.0	22.2
130	18.3	21.0	21.9	22.3	22.4
140	19.8	20.4	20.8	20.9	21.1
150	14.3	15.0	15.7	16.2	16.5
160	-6.9	-5.9	-4.9	-4.2	-3.9
170	-36.0	-35.0	-34.4	-34.2	-33.9
180	-60.2	-59.8	-59.5	-59.3	-59.0
190	-82.7	-82.3	-81.7	-81.5	-80.9
200	-158.7	-158.2	-157.1	-156.9	-156.3
210	-257.4	-256.4	-255.8	-255.7	-255.5

each of the 59 alternative Three Gorge reservoir configurations described in this study.

As stated earlier, the currently approved dam and reservoir configuration is as follows;
Top of dam elevation: 175 meters
Top of conservation pool elevation: 160 meters
Bottom of conservation pool elevation: 135 meters
Total flood storage capacity: 25.8 cubic kilometers

This project configuration results in a negative net flood control benefit at interest rates of 5, 7, and 9 percent, and an annual flood control benefit of $26 million for an interest rate of 9 percent.

If the primary purpose of the Three Gorge Dam is to maximize flood control benefits, the optimum project configuration for all interest rates would be a 140 meter top-of-dam height with a bottom of conservation pool elevation of 100 meters, which would yield a total flood control storage capacity of 12.1 cubic kilometers. This configuration requires a relatively small amount of permanent relocations and farmland loss, while protecting against downstream temporary relocations up to the 100-year flood.

EVALUATION OF THREE GORGE PROJECT NET HYDROPOWER BENEFITS

Energy forecasting calls for a seer, not an analyst. So much depends more upon the irrational vagaries of social and political currents than upon a rational response to the supply and demand equation that forecasting becomes a sort of psychoanalytical crap-shoot.

— William Hayes, Editor
Electrical World Magazine

INTRODUCTION

The evaluation of hydropower benefits is an extremely complex water resources analysis, due to many sources of uncertainty and the almost infinite number of possible project configurations that could be studied. A brief inspection of other sections of this chapter shows that analyses of other project benefits and costs generally have more reliable and copious information available, rely less on long-range forecasting with its inherent uncertainties, and, in general, involve much less interdisciplinary communication.

This section describes the history and configuration of the Chinese energy sector and its place in the nation's economy, and outlines the proposed solutions to current problems as set forth in the Sixth through Ninth Five-Year Plans.

This section also describes a new and greatly simplified step-by-step procedure which yields a reconnaissance-level estimate of the hydropower benefits of a large hydropower project in a developing country. This method, outlined in Table XIX, makes use of 'building blocks' of alternative thermal generating capacity and annual energy to reduce the 'universe' of possible project installed generating capacities to a number that can be studied in more detail. Three Gorge Dam is an ideal subject for this process, because its sheer size guarantees that it will have almost every conceivable type of consequence on the Chinese power system and economic sectors. Therefore, its initial 'universe' of possible configurations will be literally infinite in size. This chapter describes how this set of alternatives may be reduced to a manageable size.

TABLE XIX

OUTLINE OF METHODOLOGY:
EVALUATION OF TANGIBLE NET HYDROPOWER BENEFITS

(1) Select general project site.
Compare it to other possible hydro developments

(2) Define the power system.

(3) Define the system's current and projected resources.
(a) Compile plant data: age, operation, maintenance and
replacement costs, ramp rates, fuel costs, plant
operating modes (peaking, cycling, base load)
(b) Determine construction sequence of new scheduled plants
(c) Derive resource curve through time

(4) Define the system's current and projected loads.
Current and projected consumption by sector: residential,
commercial, industrial, electroprocess
Consider demographics: population growth, lifestyles,
climate, economic situation, price structures
Derive load curve through time. Compare to resources.

(5) Define hydro project configurations to be studied.
Total installed capacities
Individual turbine-generator installed capacities
Without-project development schemes
Various water years
Fuel cost escalations
Inflation rates
Interest rates

(6) Determine characteristics of alternative sources of power.
Define alternative projects: hydropower, coal-fired steam,
nuclear steam, combustion turbines, combined cycle, gas-
fired combustion turbine, imports, or combinations of
these
Establish the service lives of the alternatives

(7) Evaluate the costs of the alternative plants.
Construction costs of 1,000 megawatt alternative plants
Derive present worth of construction and operation costs
of a time series of alternative plants
Calculate investment costs of obtaining coal, gas and
nuclear fuel
Estimate distribution of project generation through const-
ruction and operating life
Calculate total cost of alternative thermal power

(8) Estimate the installed capacity of the proposed hydro plant.

Power planning is definitely not a static or "one-time" evaluation procedure. It is iterative, and it is necessary to frequently skip back and forth between the steps of this process. Additionally, a hydropower study must be carried out with other project purposes in mind, many of which are not synergistic with hydro or with each other. For a large multiple-purpose project such as Three Gorge Dam and Reservoir, the process may be carried out literally hundreds of times before the dam is sized so that all benefits are near-optimized with respect to each other and with respect to the system.

The Power Planning Process.

The benefits of a hydropower project are not simply equivalent to the value of its electrical output, but are instead equal to the difference of costs between operating the "system" with the proposed project and without it. However, it is the author's experience that, when dealing with very large hydro projects, the difference in the costs of operating the 'with-project' and 'without-project' systems may be approximated by comparing the costs of constructing and operating the proposed hydro project and its least costly, most likely thermal alternative. It must be stressed that this method should only be used to narrow the field of possible hydro projects early in a study, thereby saving time and money. Eventually, a detailed examination of the system with the aid of an hourly production cost model will be required.

If, at the conclusion of the study, the "system" is found to be cheaper to operate with the project than without it, the project is economically feasible (although not necessarily financially feasible).

The following paragraphs describe a step-by-step load-resource analysis, whose purpose is to eventually reveal whether or not a proposed project's capacity and energy is needed by the power system. The ultimate purpose of a load-resource analysis is to compare projected power demand and available capacity so that new base-load, cycling, and peaking capacity may be properly scheduled.

Table XIX outlines the proposed method for evaluating the net hydropower benefits of a large multiple-purpose water resource project. The remainder of this section describes this process in detail.

Step 1: Select the Hydropower Site to be Examined.

The selection of the 'best' hydro project that can be built in an area is a separate study which precedes its actual economic analysis. As described in Chapter III, the Chinese government selected the Sandouping site for the Three Gorge Dam after a prolonged trading-off and bargaining process. Three Gorge Dam was found to be far superior to clusters of other large hydro projects in terms of cost, relocations, and lost farmland per installed megawatt, as Table XX demonstrates.

Step 2: Define the System.

The "system" in which the Three Gorge Dam and Reservoir project will be imbedded will vary from one project purpose to another. For example, the navigation "system" will be the Yangtze River and its ports from Chongqing to Shanghai, and will include alternative routes of transport. The "system" for hydropower evaluation will be defined as that area which consumes the project's electrical energy. The adverse 'sociological' and environmental impacts of large hydro plants

TABLE XX

COMPARISON OF FEASIBILITY INDICATORS,
THREE GORGE DAM AND HYDROPOWER ALTERNATIVES

	Three Gorge Dam	National Studies		Regional Studies		
		Study One	Study Two	Study Three	Study Four	Study Five
Capacity (MW)	13,000	17,760	12,600	14,881	7,690	6,440
Average annual energy (TWh)	70.07	77.85	54.00	64.30	37.93	31.80
Indicator (per megawatt of installed capacity)						
Farmland drowned (hectares)	0.48	8.97	10.42	9.36	1.36	1.22
Permanent relocations (persons)	26	136	122	137	32	31

Reference: MWREP, 1983b. Backup information in (Clowes, 1987c).

are usually associated with the construction and filling of a reservoir, and so occupy a different 'system' than that which receives hydro benefits. These impacts are described in Chapters V and VI.

According to the Chinese government, North and South China will depend primarily upon their own energy reserves to meet their future energy needs. North China's capacity additions will basically be coal-fired thermal plants. For the purpose of hydropower analysis, the Chinese government has defined the Three Gorge service area as Sichuan Province, Central China (Guangdong, Guangxi, Henan, Hubei, and Hunan Provinces), and Eastern China (Anhui, Fujian, Jiangsu, Jiangxi, Shandong, and Zhejiang Provinces and Shanghai City) (MWREP, 1983b).

This "system" will not include rural areas, because the Chinese government is implementing an effective policy of rural electrical

self-sufficiency, as described in Chapter III. In any case, the costs of a distribution system to the many small villages and cooperatives scattered throughout the countryside would be prohibitive. Therefore, the Three Gorge 'system' is defined as the larger population and industrial centers in the twelve Provinces listed above, and in the city of Shanghai.

Step 3: Define the System's Current and Projected Resources.

Overview. The power system and its current and planned electrical generation stations must be evaluated in order to determine how well they can meet anticipated power demands. The plants are examined with respect to age (projected retirement dates and increasing operation and maintenance costs), possible restrictions on fuel use, price increases, and nonstructural measures such as conservation and power imports. The future operating mode of each plant in the load curve (base load, cycling, and peaking) is also evaluated, and a resource curve for the next twenty to thirty years is derived. This year-by-year compilation of available resources is compared to future loads to predict capacity and energy shortfalls. From this information, the construction sequence for new power plants may be determined (Mittelstadt).

Rural Energy Consumption. In China, estimates of the annual local rural consumption of peat, animal waste, and firewood are as much as 350 million equivalent tonnes of coal (Chu-Yuan, 1984). This study assumes that the construction of the Three Gorge Dam will have no effect upon the consumption of these fuels, because the energy produced by these small plants is put to local use. Therefore, this study will

deal only with the output of existing and planned commercial thermal plants and hydro stations in the Three Gorge service area.

Step 4: Define the System's Current and Projected Loads.

The consumption of electricity can be divided into several categories: residential, commercial, industrial, irrigation, and electroprocess use. Current and past consumption data by category must be examined, and then use for each category is projected over the next twenty to thirty years. Electricity consumption may vary with many other factors, such as population growth and demographics, climate, economic growth, industrial base, and prevailing price structure. All uses are summed by year to determine total future energy consumption over time. The Ministry of Water Resources and Electric Power has provided approximate historical energy consumption by sector within the Three Gorge service area. Although this table is somewhat useful for predicting future trends, the actual analysis that must be performed by the Chinese government will necessarily be much more detailed.

The current average peak daily load in the Three Gorge service area is about 33,000 megawatts, which more than exceeded available generating resources. This peak load is expected to grow to at least 105,000 megawatts by the year 2005 (see Table XXI).

Under the currently favored Three Gorge project power plan, energy from the 6,000 megawatt right-bank powerhouse will be dedicated to Eastern China, and will be transmitted 1,180 kilometers to the vicinity of Shanghai via two 500 to 600 kilovolt DC lines or two 750 kilovolt AC lines (MWREP, 1985b). After transmission losses, these areas will receive about 5,460 megawatts (Farr).

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TABLE XXI

PROJECTED MAXIMUM LOADS AND REQUIRED GENERATING
CAPACITY IN THE THREE GORGE SERVICE AREA
(median load growth scenario)

Year	Maximum Expected Loads (MW)			Required Generating Capacity (MW) *			
	Sichuan Province	Central China	Eastern China	Sichuan Province	Central China	Eastern China	Service Area
1980	3,310	9,920	13,660	3,970	11,900	16,400	32,270
1981	3,425	10,120	14,200	4,110	12,140	17,040	33,290
1982	3,550	10,325	14,760	4,260	12,390	17,710	34,360
1983	3,680	10,540	15,330	4,420	12,650	18,400	35,470
1984	3,790	10,690	15,850	4,550	12,830	19,020	36,400
1985	3,910	10,850	16,370	4,690	13,020	19,640	37,350
1986	4,030	11,010	16,920	4,840	13,210	20,300	38,350
1987	4,150	11,170	17,480	4,980	13,400	20,980	39,360
1988	4,280	11,330	18,070	5,140	13,600	21,680	40,420
1989	4,410	11,490	18,670	5,290	13,790	22,400	41,480
1990	4,550	12,590	19,290	5,460	15,110	23,150	43,720
1991	4,900	13,490	20,740	5,880	16,190	24,890	46,960
1992	5,290	14,450	22,310	6,350	17,340	26,770	50,460
1993	5,700	15,480	23,990	6,840	18,580	28,790	54,210
1994	6,140	16,580	25,800	7,370	19,900	30,960	58,230
1995	6,620	17,760	27,740	7,950	21,310	33,290	62,550
1996	7,140	19,020	29,830	8,570	22,820	35,800	67,190
1997	7,700	20,380	32,080	9,240	24,460	38,500	72,200
1998	8,300	21,830	34,500	9,960	26,200	41,400	77,560
1999	8,940	23,380	37,090	10,730	28,060	44,510	83,300
2000	9,640	25,050	39,890	11,570	30,060	47,870	89,500
2001	10,470	27,050	42,710	12,560	32,460	51,250	96,270
2002	11,370	29,210	45,720	13,640	35,050	54,860	103,550
2003	12,360	31,540	48,950	14,830	37,850	58,740	111,420
2004	13,420	34,050	52,410	16,100	40,860	62,890	119,850
2005	14,580	36,770	56,110	17,500	44,120	67,330	128,950
2006	15,840	39,700	60,070	19,010	47,640	72,080	138,730
2007	17,210	42,870	64,310	20,650	51,440	77,170	149,260
2008	18,700	46,290	68,850	22,440	55,550	82,620	160,610
2009	20,310	49,990	73,720	24,370	59,990	88,460	172,820
2010	22,070	53,970	78,920	26,480	64,760	94,700	185,940

* A twenty percent reserve margin is assumed.
  Supporting calculations are located in (Clowes, 1987c).
  References: MWREP, 1983a and 1983b; Smil, 1978; Mittelstadt.

The output from the left-bank powerhouse will be divided between Central China, which will receive 5,810 megawatts (after losses) at Wuhan through 400 kilometers of 500 kilovolt AC lines, and Sichuan Province, which will receive 1,000 megawatts (MWREP, 1983b; USBR, 1984).

Step 5: Define the Hydro Project Configurations to be Evaluated.

The title of 'largest power station on earth' is currently held by the Itaipu hydroelectric project on the Parana River between Brazil and Paraguay. This complex cost $12.7 billion and required eight years to construct. Its eighteen 700 megawatt turbine-generator sets (totalling 12,600 megawatts) produce 79 terawatt-hours of energy annually (Sarkaria).

By comparison, the currently favored configuration of the Three Gorge Dam calls for the installation of twenty-six 500-megawatt generators in two powerhouses, for a total installed capacity of 13,000 megawatts. Maximum output of each generator, with 15% overload, would be 575 megawatts. Annual power production will be about seventy terawatt-hours, valued at about $2.5 billion. It is interesting to note that this annual generation is equivalent to the total annual output of all of the 90,000 hydropower stations existing in China at the end of 1985.

This specific installed capacity was produced through an informal "trading-off" procedure during several conferences of high-level Chinese engineers and administrators (see Chapter III for details). The Chinese have investigated capacities ranging from 6,000 to 30,000 megawatts, and dam heights from 150 to 260 meters. The current limits

of installed hydro capacities being studied are 13,000 megawatts to 25,000 megawatts.

If the 13,000 megawatt alternative is constructed, 2,000 megawatts of capacity will come on line during years 12 to 17 of project construction, and 1,000 megawatts will come on-line in the 18th year. Provisions have been made to install 3,000 additional megawatts of generating units in a third powerhouse on the right bank of the river, should such a need arise. Average annual energy from these six units would be about 8,000 gigawatt-hours (Clowes, 1987c).

There are literally an infinite number of possible combinations of dam height, installed capacity, and equipment variation available for any project. As with most multiple-purpose water resource projects, flood control takes precedence over hydropower generation at Three Gorge Dam. Assuming that the dam height and rule curve have already been specified by flood control studies, a preliminary study of Three Gorge hydropower benefits might include the following alternatives;

* installed capacities from 1,000 megawatts to 31,000 megawatts, in 1,000 megawatt increments;
* several different 'without-project' power system development scenarios (example: 85 percent coal, 10 percent nuclear, and 5 percent combustion turbine); and
* four different interest rates.

A more refined study would consider such factors as combinations of turbine size, various water years, and different inflation rates, real fuel cost escalation rates, and future load years. Such a detailed study would have to examine or eliminate from consideration more than one million possible factor combinations, and demonstrates vividly why the universe of possible project alternatives must be narrowed to a manageable number as early as possible in the study.

This study will examine Three Gorge project installed capacities from 1,000 megawatts to 31,000 megawatts at four different interest rates, and for various bottom and top of conservation pool elevations.

Step 6: Determine the Characteristics of Alternative Sources of Power.

Define the Alternative Thermal and Hydro Projects. For the purposes of this study, an 'alternative project' is defined as one of a number of combinations of generating stations that could be constructed to produce power in the place of Three Gorge Dam, should it be permanently shelved.

The thermal or "non-structural" alternative to the hydro project depends upon its mode of operation (base-load or peaking). This mode of operation may vary throughout the year. Alternatives to be investigated may be one or more of the following;

* one or more hydropower plants,
* one or more thermal plants,
* one or more combustion turbines,
* one or more combined cycle plants,
* purchases and imports,
* conservation, or
* a combination of two or more of the above.

If a load-growth analysis indicates that a capacity or energy shortfall will occur without additional powerplant construction, the planner must determine what type of generating plant can provide the needed generation at the lowest cost. Hydro and thermal plants must be compared with identical tax burdens, interest rates, and depreciation accounting methods in order to produce an equitable analysis.

Hydropower is not preferable if its economic advantages are derived from artificial means such as taxes or interest breaks (Kuiper).

The Thermal Alternative to Three Gorge Dam. During the summer
flood season of six months, the Three Gorge powerplant would provide
base load power, and in the dry winter season, it would operate in a
peaking mode. In keeping with Chinese power planning theory, firm
energy and secondary energy possess essentially identical values in a
severely underinstalled power system. The Ministry of Water Resources
and Electric Power has provided rough estimates of Three Gorge project
firm energy, but does not distinguish firm from secondary energy
benefits in their calculations (MWREP, 1983a and 1983b; USBR, 1984).

As discussed earlier in this chapter, the Chinese government
intends to phase out oil-fired plants. Additionally, the Chinese have
performed studies that have shown that a hydropower alternative to
Three Gorge Dam would not be feasible (see Table XX). Therefore, it
appears initially that some mix of nuclear and coal steam and gas
combustion turbine would be an appropriate mix for the alternative
project.

Establish the Service Lives of the Alternative Projects. The
economic life of the Three Gorge Dam is assumed to be 100 years. The
economic lives of the coal-fired and nuclear thermal and gas-fired CT
alternatives are expected to be 25 to 30 years (MWREP, 1983a; USBR,
1984; TAG).

Step 7: Evaluate the Costs of the Thermal Alternatives.

Introduction. The coal-fired portion of the thermal alternative
to Three Gorge Dam would be built in southeast Shanxi Province, which
is about as far from the study's demand center (East China) as is Three
Gorge Dam. The distance to Central China for the thermal alternative

is slightly longer than for Three Gorge (MWREP, 1983b). It is assumed that the nuclear portion of the thermal alternative would be built in the vicinity of the load centers. Overall, it appears that transmission system construction costs and line losses would be approximately equal for Three Gorge and its thermal alternative, but this assumption should be studied in more detail.

Hydropower benefits are based upon two components of the costs of the thermal alternative (Mittelstadt);

(1) The capacity benefit, which consists of fixed thermal
    plant operating costs and investment costs;
    *   construction cost,
    *   interest during construction,
    *   the cost of constructing supporting mines, and
    *   fixed operation, maintenance, and replacement (OM&R)
        costs.

(2) The energy benefit, which consists of fuel costs and
    variable operation, maintenance, and replacement (OM&R)
    costs.

The process of evaluating these variables is extremely detailed in nature and very time-consuming. Therefore, a new procedure, using 'building blocks' of 1,000 megawatt alternative plants and one terawatt-hour of annual generation, is proposed. The calculations for this streamlined process are outlined below (Clowes, 1987c).

Step 7A. Calculate the investment cost of four alternative 1,000 megawatt generating plants (hydropower, coal-fired steam, and nuclear steam and gas-fired combustion turbine). Interest during construction is calculated from the middle of each construction year to the plant on-line date for interest rates of three percent, five percent, seven percent, and nine percent.

Hydro.   The annual distribution of the alternative 1,000 megawatt
         hydropower plant construction cost is based upon an
         examination of the costs of six large hydropower plants
         built since 1983 and five others that are now in advanced
         design studies. The total capacities of these plants is
         11,995 megawatts, and average time to first power is ten
         years. Construction cost is $932 per installed kilowatt.

Coal.   The annual distribution of the construction cost of the
         alternative 1,000 megawatt coal-fired steam plant is based
         upon information furnished by the MWREP in their 1983
         Feasibility Report. Average time to first power is six
         years, and average construction cost is $514 per installed
         kilowatt.

Nuclear. The annual distribution of the alternative 1,000 mega-
         watt nuclear steam plant construction cost (improved-
         technology light-water reactor) is provided by EPRI (TAG).
         Average time to first power is six years, and average
         construction cost is $1,685 per installed kilowatt.

Gas CT. The construction time of a modern gas-fired combustion
         turbine is one year, so no interest during construction
         calculations are necessary. The constuction cost for 75
         megawatt CT plants is $270 per kilowatt (TAG).

         Step 7B.   Derive the present worths of the construction and

operation costs of a time series of each type of plant, based upon

their varying service lives, for a range of interest rates.

Hydro.   It is assumed that total replacement of the two 500-megawatt
         turbine-generator units takes place after 30 years
         (Mittelstadt). The costs of this replacement are based
         upon fabrication costs of about $7,400 per ton (MWREP,
         1983b), and total unit weights of about 6,400 tons
         (C3GPDC). Operation and maintenance costs are about $3
         million per year (Clowes, 1987b).

Coal.   The Chinese government has set annual operation, mainte-
         nance, and replacement (OM&R) costs equal to 3.35 percent
         of accrued coal plant investment costs upon commencement of
         operation (MWREP, 1983b; USBR, 1984). This is equal to $17
         million annually for each alternative 1,000 megawatt coal
         plant, beginning in 2001. This figure is cross-checked by
         the guidelines given by EPRI in their Technical Asssessment
         Guide. In view of their 25-year economic life, several
         series of these 1,000 megawatt coal-fired steam plants are
         constructed and retired during the economic life of the
         Three Gorge Dam.

Nuclear.   Beginning in 2001, annual costs include $37 million annually
          for OM&R for a 1,000 megawatt plant (EPRI). In view of
          their 30-year economic life, three series of these 1,000
          megawatt nuclear steam plants are constructed and retired
          during the economic life of the Three Gorge Dam. Beginning
          with the project on-line date of series number 2, a plant
          decommissioning cost equal to one-half of the plant's
          construction cost without IDC (about $840 million) is
          assessed for the previous plants in the series. It is
          assumed that this cost occurs in only one year, although in
          reality it would be spread out in a relatively uniform
          manner over a period of from four to six years.

Gas CT.   The lifetime of a gas-fired combustion turbine plant is
          about 30 years. The fixed operation and mainte- nance
          costs for such a plant are $0.40 per kilowatt per year, or
          $400,000 per 1,000 megawatts per year (TAG).

Step 7C.   Calculate the investment costs of constructing mines
capable of supporting one terawatt-hour of coal-fired and nuclear steam
generation per year, and derive the present worth of the fuel
production required to support this generation throughout the 100-year
expected life of the Three Gorge project.

Interest during construction (IDC) is calculated from the middle
of the construction year to the plant on-line (POL) date.

The pattern of on-line dates for alternative 1,000 megawatt
coal-fired and nuclear steam plants and gas-fired CT's in the thermal
alternative to Three Gorge Dam is unknown. Therefore, it is assumed
that each thermal plant will bear a proportionate share of the system
load during the time that Three Gorge project hydropower units would
have come on-line (2001-2007).

Coal.   The updated cost of constructing a large Shanxi coal mine is
        $106 per annual additional tonne of coal production
        (Smil, 1978). The conversion efficiency of standard
        Shanxi coal is 0.38 kilograms per kilowatt- hour, or
        380,000 tonnes per terawatt-hour (MWREP, 1983b). This

results in a construction cost of $40 million for a 380,000 tonne per year mine. The construction time for such a mine is eight years.

The updated cost of mining Shanxi coal, including the raw coal price, national government subsidy, and transportation to the powerplant, is $43.60 per tonne (MWREP, 1983b). In view of the conversion efficiency stated above, this is equal to a fuel cost of $16.6 million per terawatt-hour of generation. Real fuel cost escalation is assumed to be three percent for all interest rates until 30 years from the present, and zero thereafter (Mittelstadt).

Nuclear. World uranium fuel prices were about one dollar per million BTU in 1984. The average heat rate for uranium is about 10,500 BTU per kilowatt-hour (EPRI). These figures yield a real 1987 fuel cost of about 1.1 cents per kWh, or $11.1 million for one terawatt-hour. Real fuel cost escalation is assumed to be three percent for all interest rates until 30 years from the present, and zero thereafter.

Gas CT. The heat rate of standard gas-fired combustion turbines is about 11,600 BTU per kilowatt-hour. The general worldwide cost of natural gas is about $5.00 per million BTU (TAG). This translates to a present fuel cost of about $58 million per terawatt-hour of electrical generation. Real fuel cost escalation is assumed to be three percent for all interest rates until 30 years from the present, and zero thereafter.

Step 7D. Establish the points at which nuclear and coal generation and coal and gas-fired combustion turbine generation are equally expensive to operate. This information is used to determine the thermal alternative for each increment of Three Gorge project generation. The results of these calculations are shown in Table XXII (Clowes, 1987c).

This information is used in simultaneous equations that determine the "break-even point" between the coal steam and gas combustion turbine thermal alternatives and the coal steam and nuclear steam thermal alternatives. The average generation for which a 1,000

TABLE XXII

UNIT COSTS OF CONSTRUCTING AND OPERATING
THREE GORGE PROJECT THERMAL ALTERNATIVES

Interest Rate	1,000 Megawatt Plant Series Annualized Construction and Operations Costs				Mines/Fuel Cost to Support 1 TWh/Year Energy Production		
	Hydro	Coal	Nuclear	Gas CT	Coal	Nuclear	Gas CT
3%	26	30	99	11	23	16	72
5%	31	30	94	9	17	12	51
7%	36	25	90	8	13	11	35
9%	38	23	90	7	11	9	26

megawatt increment of alternative coal-fired generation will be equivalent in cost to a 1,000 megawatt increment of gas-fired combustion turbine generation is as follows;

3 percent - 0.388 terawatt-hours
5 percent - 0.618 terawatt-hours
7 percent - 0.773 terawatt-hours
9 percent - 1.067 terawatt-hours

Due to the abundance of coal in China, and the high construction and operation costs of nuclear plants, the remaining set of simultaneous equations reveal that a coal-fired plant is cheaper to construct and operate than a nuclear plant at all points in the loading order.

Therefore, nuclear plants will no longer be a consideration in these calculations. From this point onward, the thermal alternative to Three Gorge Dam is coal-fired steam and gas-fired combustion turbines, in a mix to be determined in this analysis.

Step 7E. Establish the distribution of Three Gorge project energy generation through its construction period and operating life. Using established hydrologic data, route average monthly flows for the Yangtze River through the various Three Gorge powerhouse configurations. The following information is required for routings that take place during and after project construction;

* project rule curves
* average monthly flows
* reservoir elevation-area-capacity table
* turbine discharge/head/power relationships
* tailwater elevation curve
* unit efficiency/head curve
* unit maintenance and emergency outage rates

The unit on-line schedule was derived from the dry-year estimate of energy given by the MWREP. The first two 500-megawatt generating units come on line right at the end of year 11 of construction. Thereafter, an average of four units will come on-line in each additional year. The first ten units will be put on-line relatively early, because their incremental return will be much greater than subsequent units. These first ten units will be running at almost a 100 percent plant factor for their first few years. Pool filling is complete at the end of year 14. At this point, turbines may begin to operate within their design head range.

These calculations were modified to reflect (a), an updated annual energy estimate, (b) changes in rule curve elevation with resulting additional reservoir impoundment and discharges, and (c) the assumption that Three Gorge Dam, during its construction and subsequent operating life, would be functioning on a succession of "average" water years.

The author's experience with other large hydropower studies has shown that, at least for a preliminary study, this assumption will not lead to excessive error. An in-depth study would require the use of complex production cost and hydrologic models in order to obtain true values for representative high, low, and median water years. This type of study has not yet been undertaken for Three Gorge Dam.

Step 7F. Calculate the total and incremental annual present worth of alternative powerplant construction and fuel production costs for several on-line dates and interest rates. Using this information, tally the annualized costs of all of the Three Gorge project thermal alternatives.

In order to produce costs for the alternative thermal systems, the amount of energy generated by the Three Gorge project must be determined. By examining the generation-duration curve for the Three Gorge Dam, one can determine the average amount of generation that each incremental 1,000 megawatts of installed capacity will produce each year (Clowes, 1987c). One example of this type of information is shown in Table XXIII, and a generation-duration curve for the project is shown in Figure 6.

As each additional unit is called into service, it will produce less annual energy, due to the tapered shape of the generation-duration curve (Mittelstadt). In other words, higher flows are available during lesser percentages of time.

The generation-duration curve is the result of a complex and information-intensive study which uses flow-duration curves, a tailwater curve, and turbine characteristics to produce a plot of total
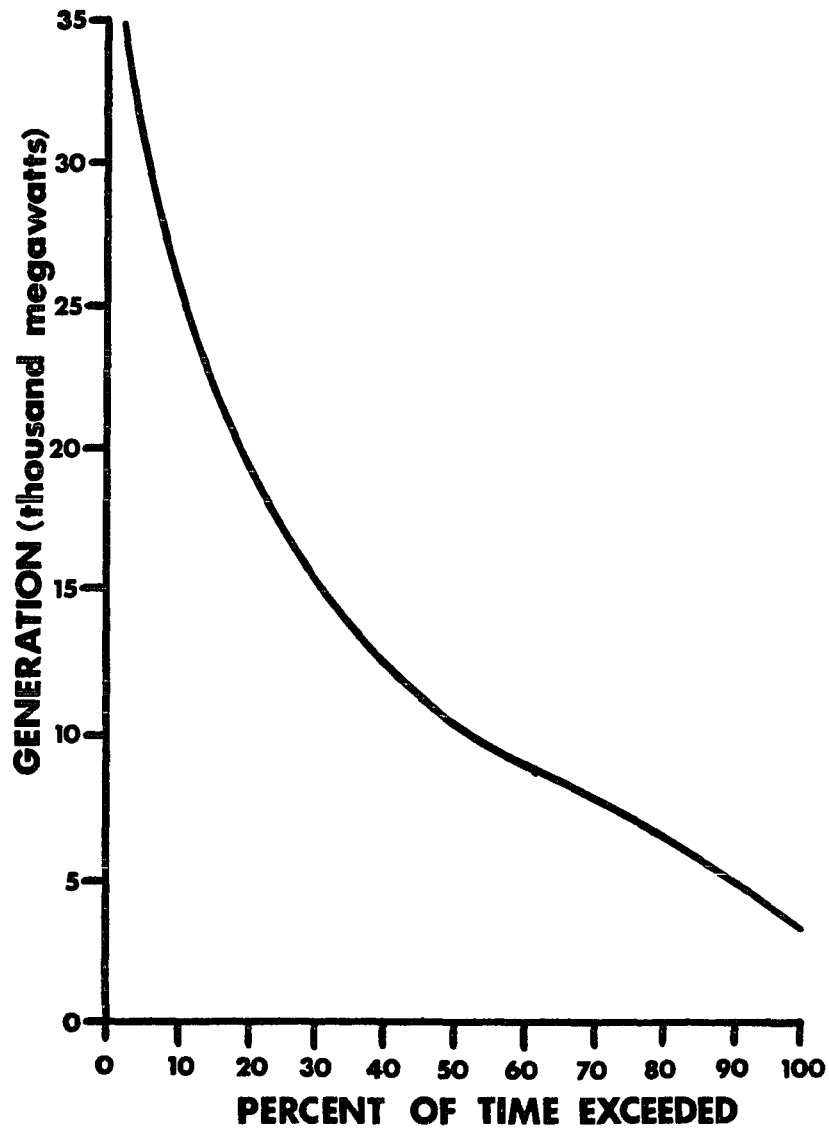
Figure 6. A generation-duration curve for the Three Gorge project. This is a plot of total project generation vs. the time that this generation is equalled or exceeded during the months of November and December for a top of conservation pool level of 160 meters. The area under the curve represents average project generation under these conditions.

TABLE XXIII

ANNUALIZED BENEFITS AND COSTS OF INCREMENTAL THREE
GORGE 1,000 MEGAWATT BLOCKS OF INSTALLED CAPACITY

(currently approved reservoir configuration)

Installed Capacity (megawatts)	Annual Energy (TWh) Incremental	Total	Incremental Annual ($millions); Average Costs	Benefits at: 3%	5%	7%	9%
1,000	8.76	8.76	11	217	162	124	105
2,000	8.76	17.52	27	216	161	120	98
3,000	8.66	26.18	13	213	159	117	95
4,000	8.21	34.39	15	209	154	114	92
5,000	6.56	40.95	17	168	126	93	90
6,000	5.55	46.50	16	147	119	85	79
7,000	4.72	51.22	4	143	111	82	73
8,000	4.58	55.80	4	134	106	78	69
9,000	3.68	59.48	6	111	97	73	64
10,000	3.43	62.91	5	108	91	70	61
11,000	2.86	65.77	9	91	74	61	49
12,000	2.31	68.08	6	81	62	56	43
13,000	2.11	70.19	11	71	60	45	39
14,300	2.97	73.16	8	121	97	77	66
15,600	2.77	75.93	9	113	91	71	62
18,200	4.69	80.62	16	178	147	114	100
20,800	3.53	84.15	15	151	128	99	87
23,400	2.62	86.77	13	130	111	88	78
25,000	1.26	88.03	3	76	67	54	13
27,000	1.12	89.15	23	66	40	31	21
29,000	0.69	89.84	25	40	21	18	11
31,000	0.41	90.25	28	20	8	9	4

The broken line in the lower right-hand corner of this table
represents approximately the point at which the incremental costs of
alternative coal-fired steam and gas-fired combustion turbine
generation are about equal. The bold numbers to the right of this line
are incremental costs for gas-fired combustion turbine generation.

project electricity generation vs. percent of time equalled or exceeded

for a specific headwater elevation. Naturally, if a reservoir rule

curve specifies that the reservoir top of conservation pool fluctuates

during the year, several generation-duration curves may be required. A

detailed example of generation-duration curve derivation may be found

in Chapter 5 of the Corps of Engineers' Engineering Manual EM 1110-2-1701, Hydropower.

Step 8: Set the Installed Capacity of the Proposed Hydro Project.

The above calculations show that the most desirable thermal alternative to Three Gorge Dam, regardless of installed capacity or average annual generation, is that mix which includes coal-fired capacity for base-load and gas combustion turbines for peak loading. It is interesting to note that this rule holds true for all of the interest rates examined, because the initial heavy cost of constructing nuclear steam plants offsets cheaper nuclear fuel costs, even after the lesser discounting at lower interest rates.

The final step in the power study process is to select the size of the Three Gorge powerplant, using the cheapest thermal project as an alternative. This is accomplished by examining the incremental benefits and costs of each succeeding 1,000 megawatt turbine-generator unit installed at the project. Table XXIII shows the results of this analysis for the currently approved Three Gorge reservoir configuration (Clowes, 1987c).

The 26th and 27th 1,000 megawatt Three Gorge turbine-generator units would produce an average incremental energy of 1.12 terawatt-hours annually. The most likely, least costly thermal alternative to these units would be coal-fired steam at three percent and five percent, and gas-fired combustion turbines at seven percent and nine percent. The table also shows that the 26th and 27th units would not generate enough energy to support their cost at an interest rate of nine percent.

The final result of this study shows that, for the currently approved reservoir configuration, the optimum installed hydropower capacity is 29,000 megawatts at three percent, 27,000 megawatts at five and seven percent, and 25,000 megawatts at nine percent.

Summary: Hydropower Net Benefit Analysis.

Background Information. When hydropower costs and benefits are tabulated in isolation from other project purposes, it becomes apparent that an extremely large electrical generating capacity could be economically supported at the dam. The incremental benefits of even the 25th 1,000 megawatt turbine-generator unit exceeds the annualized costs of the necessary additional equipment at all interest rates examined.

Installed Hydropower Capacity. The currently approved installed hydropower capacity at Three Gorge Dam is 13,000 megawatts. If the planned top-of-dam elevation and conservation pool ranges are accepted as inviolable, increasing the installed capacity of the project could increase net benefits by about fifty percent (47 percent increase at three percent interest, 49 percent increase at five percent interest, 50 percent increase at seven percent interest, and 46 percent increase at nine percent interest) (Clowes, 1987c).

Table XXIV and Figure 7 show the results of a sensitivity study which determined Three Gorge project annual hydropower net benefits at seven percent interest for twelve different pool elevations and 22 different installed capacities.

Net benefits for this reservoir configuration are maximized with an installed hydropower capacity of in excess of 25,000 megawatts,

assuming that the technology required for the construction of 1,000 megawatt turbine-generator units will be available at the turn of the century. If this capability does not exist, a maximum of 18,200 megawatts could be installed with current world state-of-the-art turbine technology. The net hydropower benefits in this case would be increased by 22 percent at three percent interest, 23 percent at five percent interest and seven percent interest, and 24 percent at nine percent interest (Clowes, 1987c).

If the currently approved elevations for the top of dam (at 175 meters) and the top of conservation pool (at 160 meters) are adhered to, annual net hydropower benefits could be increased from five to nine percent, depending upon interest rate, merely by raising the bottom of conservation pool elevation from 135 meters to 140 meters (Clowes, 1987c).

For each dam height, total net project benefits are maximized by holding the conservation pool at the highest possible level throughout the year, except for certain configurations that are obviously infeasible (i.e., holding the pool at a constant elevation of five meters below the top-of-dam height). This is due to the fact that hydropower benefits dominate all other benefits by their sheer magnitude.

EVALUATION OF THREE GORGE PROJECT NET NAVIGATION BENEFITS

Introduction.

Commercial navigation benefits are based on savings to shippers. In the United States, the Transportation Act of 1966 specifies the

TABLE XXIV

ANNUALIZED THREE GORGE PROJECT NET HYDROPOWER BENEFITS

(benefits given in $millions)

Seven Percent Interest

Installed Capacity (megawatts)	Top of Conservation Pool Elevation (meters)					
	90	100	110	120	130	140
1,000	52	111	118	118	118	118
2,000	75	152	184	230	233	241
3,000	83	161	216	282	297	355
4,000	80	170	238	315	332	439
5,000	73	174	256	336	354	512
6,000	65	177	275	358	377	581
7,000	69	190	305	392	432	653
8,000	74	206	317	427	476	722
9,000	77	220	331	460	517	781
10,000	82	236	341	495	557	831
11,000	81	246	356	521	595	876
12,000	80	255	370	549	632	922
13,000	80	265	383	577	668	978
14,300	82	280	391	611	714	1,042
15,600	85	292	399	647	758	1,104
18,200	96	322	421	723	843	1,199
20,800	109	346	433	747	921	1,284
23,400	122	366	430	758	984	1,361
25,000	132	382	419	754	1,021	1,371
27,000	126	381	420	761	1,038	1,390
29,000	116	373	419	764	1,043	1,401
31,000	104	363	417	765	1,040	1,406

TABLE XXIV (continued)

ANNUALIZED THREE GORGE PROJECT NET HYDROPOWER BENEFITS

(benefits given in $millions)

Seven Percent Interest (continued)

Installed Capacity (megawatts)	Top of Conservation Pool Elevation (meters)					
	150	160	170	180	190	200
1,000	117	117	117	117	116	116
2,000	241	241	242	240	239	239
3,000	355	358	362	360	358	358
4,000	457	479	483	481	480	480
5,000	537	572	594	597	600	600
6,000	611	654	676	704	711	720
7,000	694	739	758	799	836	875
8,000	766	823	846	888	929	987
9,000	834	896	926	975	1,016	1,072
10,000	900	968	996	1,056	1,104	1,147
11,000	945	1,024	1,057	1,117	1,172	1,220
12,000	990	1,069	1,111	1,171	1,226	1,301
13,000	1,035	1,118	1,165	1,226	1,294	1,354
14,300	1,096	1,189	1,225	1,298	1,354	1,425
15,600	1,145	1,265	1,286	1,363	1,428	1,502
18,200	1,249	1,379	1,410	1,495	1,570	1,653
20,800	1,342	1,478	1,516	1,609	1,690	1,781
23,400	1,424	1,566	1,609	1,707	1,794	1,890
25,000	1,440	1,620	1,666	1,767	1,856	1,955
27,000	1,465	1,651	1,707	1,814	1,906	2,006
29,000	1,486	1,669	1,727	1,840	1,933	2,037
31,000	1,493	1,678	1,733	1,854	1,943	2,050
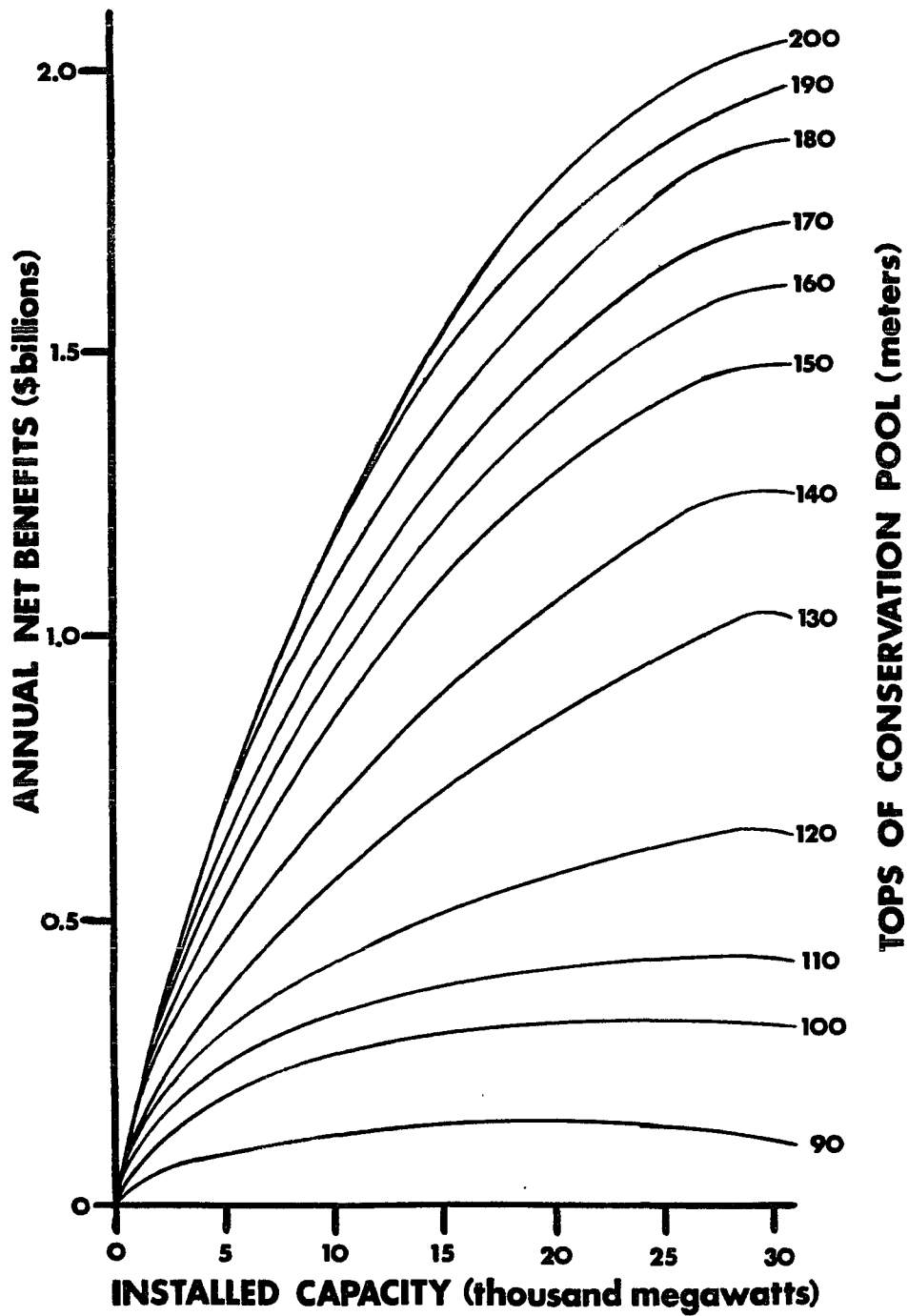
Figure 7. Three Gorge project net hydropower benefits for alter-
native top of conservation pool elevations and total
electrical generating capacities.

basis for determining the savings in transportation cost as the difference between rates which would be charged on the proposed waterway and freight rates prevailing at the time of study for movement by alternative means.

Benefits for recreational navigation are based on estimates of boater's net willingness to pay, derived by either the travel cost, survey, or unit day valuation approach. The basis for evaluating charter fishing craft benefits is considered similar in character to that for fishing vessels; i.e., the increase in net income is the benefit. Recreational boating is expected to be minor in scope on the Three Gorge Reservoir, with the exception of state-run tour vessels (Zhou).

Assessing the Without-Project Condition.

Direct benefits may be obtained by assessing the cost of the most likely alternative modes of transportation. This will basically be a with-project and without-project analysis. The analysis of the without-project condition must include, as a minimum, the following factors;

* interest, operation, maintenance and replacement, and depreciation of existing barges and tugs and loading and unloading facilities (Kuiper).

* the cost of extra fuel and time of road and rail travel compared to river travel, including transfer from mode to mode. The benefit is the cost of actual resources saved (by carriers, not customers) in the act of transporting goods,

including wear and tear on vehicles. Tariffs not charged to customers are not counted as benefits (James).

* the cost of overland transport of that material that is attracted to the river navigation system as a result of the project. This amount must include both new transportation to the region and transportation attracted from other modes. New regional traffic is assessed by the willingness-to-pay criteria (Howe, Charles).

* the development of businesses that would not exist in the without-project condition. This benefit does not include those existing businesses that merely shift location due to construction of the project.

* the development of recreation facilities upstream due to construction of the project.

Information on the last three points regarding the Three Gorge Dam and Reservoir is almost completely unavailable to agencies or individuals outside the People's Republic of China. However, the large majority of the costs of operating a transportation system in the without-project condition are contained in the first two points - fuel and operation and maintenance costs. Because some information is available on the costs of operating world navigation and overland transportation systems, fuel and system operation and maintenance (O&M) costs will form the basis of both the with- and without-project costs in this study.

Navigation Costs.

The costs of a navigation project include the following items;

* Direct Costs;

  * construction of harbors, locks, and navigation aids, and

  * operation and maintenance, including lock operation and repair, traffic control, dredging, and upkeep of harbors.

*   <u>Indirect Costs;</u>

    *   the value of flood control and water supply benefits foregone as a result of allocation of storage to navigation

    *   the value of hydropower benefits foregone due to passage of water for lockage operations. For example, the Three Gorge locks (165 meter top-of-dam elevation), which measure 280 X 34 X 3.2 meters, will lift vessels an average of 71.8 meters (US3GWG). At an average water usage of about 230 million cubic meters annually, a continuous total of about 4,750 kilowatts of generating capacity, worth about $1.46 million, will be lost each year. Since this amount of energy is equivalent to less than 0.05 percent of the total installed capacity of Three Gorge Dam, it will be neglected for the purposes of this study.

    *   costs to alternative means of transportation in the form of greater bridge maintenance costs and delays for bridge openings.

    *   the most efficient operation of the Three Gorge powerhouses for peaking purposes would result in downstream water level fluctuations of about one meter per hour. Changes of only 0.3 meters per hour would be ideal for navigation, but such a restriction may severely impede Three Gorge powerhouse peaking operations (US3GWG).

<u>Sizing a Navigation Channel.</u>

In general, a deeper, wider navigation channel cuts friction resistance and can accomodate larger, more efficient vessels. In addition, delays caused by congestion are decreased. However, deep channels are notoriously difficult and expensive to maintain, and the business of finding the balance point between benefits and maintenance costs is a tricky one indeed.

The cost of navigation to individual carriers is largely a function of the amount of fuel that vessels must burn in order to transport their cargo. In general, friction resistance is decreased by wider, deeper channels and by lower speeds. Smaller channels increase

congestion and the possibility of collision. Straighter channels shorten point-to-point routes but also increase water speed due to an increase in average channel slope. This increase in velocity decreases the cost of moving goods downriver, but increases upriver costs. Current velocities in excess of two meters per second generally render navigation uneconomical (James).

Wider channels allow larger tows and increase barge-tow maneuverability, and so fewer towboats are needed per barge. The Corps of Engineers generally maintains a minimum channel width of ninety meters and a channel depth of from three to four meters in the United States. The European standard for channel depth is four meters. Increased depth means greater dredging costs per foot, but also causes less viscous drag on the tows and barges. A great savings can be realized from dredging to greater depths so that oceangoing vessels can unload further upstream, without transferring cargo among vessels of different drafts.

Proposed Navigation Facilities at the Three Gorge Dam.

The proposed permanent navigation facilities at the 175-meter dam would consist of a double-line, three-step lock of capacity 16,000 tonnes. Each of the three chambers would have dimensions of 280 meters length by 34 meters width by 3.2 meters depth. A single shiplift would be installed before construction begins. It would have a capacity of 2,300 tonnes and would have dimensions of 140 meters length by 16 meters width by 3.2 meters depth (MWREP, 1983b). Maximum total lift would be 87 meters for the 165 meter dam, the highest in the world.

(The current record holder is John Day Lock on the Columbia River, a single-lift system with a 32 meter lift (ENR, 1984)). Navigation during project construction would take place in the widened diversion channel, in a temporary shiplock of 240 meters length by 24 meters width by 4 meters depth, and in the shiplift.

The maximum allowable length of vessels in the shiplift will be 131 meters, and in the locks 255 meters. Eventually, the locks will cycle an average of 20.6 times per day and the lift will cycle about 26.0 times per day, for a total annual capacity of 50 million tonnes in the locks and 4.6 million tonnes in the lift (MWREP, 1983b).

A secondary, but still very substantial navigation-related benefit would occur in the Shanghai area, where shoaling is a serious obstacle to navigation, and threatens to cut off access to the world's largest steel mill. At this time, ocean-going vessels are limited to 5,000 tonnes deadweight during the low-flow season. Controlled flows from Three Gorge Dam would eliminate low flow periods that cause shoaling and would allow vessels access by covering shoals that already exist with enough water to allow passage. The annual low flow would be increased from an average of 3,540 cubic meters per second to an average of 7,500 cubic meters per second (Xianyi).

Additionally, serious shoaling exists in the river reach between Yichang and Wuhan, where the minimum navigable depth of three meters cannot be maintained during the low-flow season. Three Gorge Dam would increase this depth to a minimum of five meters year-round (Xianyi).

Sediment Accumulation in the Three Gorge Reservoir.

About 453 cubic kilometers of river water flow through the Three

Gorges each year. The average annual sediment load in this water is 472 million tons, or about 1.17 kilograms per cubic meter. About 99 percent of this material is fine-grained solids in suspension. During the project's first eighty years of operation, about 28 percent of this sediment will be passed through sediment sluices, for a total accumulation of 11.1 cubic kilometers (EW, 1985).

A high dam of 200 meters height with a normal reservoir water surface elevation of 180 meters above sea level would create a lake extending to a point about 32 kilometers upstream of Chongqing. Since lake headwaters fluctuate due to both varying inflow and dam release operations, sediment would be deposited to the extent that regular dredging would be required not only in the city's harbor, but in the 70 kilometers of lake downstream of the city. However, the Chinese government expects that this accumulation will hinder navigation for an average of only ten days per year after 70 years of project operation (USBR, 1984).

The currently approved reservoir configuration, which includes a normal reservoir water surface elevation of 160 meters, would leave a natural river channel between Chongqing and a point about 100 kilometers downstream of the city. Rule curve operation would specify an annual drawdown to 135 meters. Occasionally, during dry winters, the elevation of the pool would drop to 130 meters, leaving an open channel of more than 350 kilometers below the city. This channel reach would have to be dredged, but the costs of maintaining an open channel would be far less significant than the expense of dredging the sizable Chongqing harbor (US3GWG).

A final factor in the navigation benefits analysis is the freight carrying capacity of both the with-project and the without-project alternatives. The high dam would allow 10,000 tonne tows to travel a slackwater lake to Chongqing, while the low dam would allow tows of only half this size, since tugs would have to negotiate adverse currents over a minimum of 100 kilometers of natural river channel, even at the maximum normal water surface elevation of 160 meters.

The Navigation Net Benefit Evaluation Procedure.

Introduction. The following paragraphs describe the procedure used to evaluate Three Gorge project net navigation benefits.

Step 1: Derive With- and Without-Project Navigation Times. Information provided by the Ministry of Water Resources and Electric Power was used to calculate the time required to navigate through the Sandouping- Chongqing reach of the Yangtze River for alternative Three Gorge Reservoir elevations (MWREP, 1983b: Map 4-8). The assumed average reservoir slope was 0.0000162 meters per meter for all levels. Navigation improvement is assumed to occur over the reservoir surface from the dam itself to the reservoir headwater.

For the purposes of these calculations, the Yichang-Chongqong reach of the Yangtze River under current conditions is divided into three sections;

(1) the segment of the Three Gorges that is currently improved for navigation due to the previous construction of Gezhouba Dam. This segment extends about 20 kilometers upstream of Sandouping Island (ENR, 1980; Xianyi). The water current velocity in this lake is essentially zero;

(2) the segment of unimproved waterway through the Three Gorges, which is about 148 kilometers long. This segment extends from the head of the Gezhouba Dam Reservoir to the upstream

entrance to Qutang Gorge. The water current velocity in this segment averages 3.3 meters per second, and

(3) the remaining 435 kilometers of the Yangtze River from the upstream entrance of Qutang Gorge to Chongqing. The water current velocity in this segment averages 2.0 meters per second.

Therefore, the total travel time for a tug making a round-trip from Sandouping Island to Chongqing under current navigation conditions is approximately 150 hours, calculated as follows;

	Travel time in;			
	Segment 1	Segment 2	Segment 3	Total
Upstream Journey	1.4 hours	58.7 hours	60.4 hours	120.5 hours
Downstream Journey	1.4 hours	5.6 hours	20.1 hours	29.1 hours

The above information is used to calculate the approximate average annual round-trip time of a tug and load through the Sandouping-Chongqing reach of the Yangtze River for various Three Gorge reservoir configurations. This calculation assumes that the growing navigation volume on this reach is evenly divided among all of the months of the year, and that an equal volume of cargo is traveling upstream and downstream.

For all of the Three Gorge reservoir configurations considered in this study, a uniform rule curve is used. The reservoir is at the top of the conservation pool elevation from November 1 to January 1. From the period January 1 to April 1, the reservoir is gradually drawn down to make space for the summer Yangtze River floods. The reservoir remains at the bottom of the conservation pool elevation until October 1, and then is filled during the month of October to the top of conservation pool elevation once again.

The average transit time for each month is calculated, and these twelve transit times are themselves averaged to yield the average annual round-trip transit time.

Table XXV summarizes the with-project and without-project navigation times for all 35 Three Gorge Reservoir configurations.

Step 2: Calculate Fuel Consumption and Costs. Using parameters obtained from shipping and railroad firms, the present-worth of navigation fuel requirements and costs for a 100-hour round-trip transit from Three Gorge Dam to Chongqing over the 100-year life of the Three Gorge project is calculated (Clowes, 1987c).

A time of 100 hours was selected so that these costs could be easily adjusted depending upon the ultimate transit time, which will in turn vary greatly with Three Gorge Reservoir configuration.

The following assumptions were made regarding these calculations;

(1) This study assumes a Three Gorge project construction start date of 1989 and the beginning of full navigation facility availability in 1997.

(2) The current amount of cargo that plies the Yangtze in the Yichang-Chongqing reach is less than one million tons annually. The maximum use rate of the navigation channel will be about 50 million tons of cargo after fifty years of project operation. It is assumed that this use rate will increase uniformly during this 50-year period (USBR, 1984; C3GPDC; MWREP, 1983b).

(3) fuel costs will escalate at a rate of three percent for thirty years and will then be levelized (Mittelstadt). Since tugs generally operate at full power regardless of water current speed, the total cost of fuel will be directly proportional to the amount of 'ton-hours' of cargo shipped (Rite).

(4) for the without-project scenario, the rate of volume growth of cargo shipped between Chongqing and Yichang will remain the same for both the with-project and without-project

TABLE XXV

ROUND-TRIP NAVIGATION TIMES FOR ALTERNATIVE
THREE GORGE RESERVOIR CONFIGURATIONS

TRANSIT TIMES (Hours)

Top-of-Dam Height (meters)	Top of Conservation Pool Elevation (meters)	Bottom of Conservation Pool Relative to Top of Dam (meters)				
		-20	-25	-30	-35	-40
210	200	84.0	84.2	84.5	85.3	86.2
200	190	84.0	84.3	84.6	85.3	86.3
190	180	84.5	85.5	86.5	87.7	89.0
180	170	86.9	88.1	89.6	90.8	92.2
170	160	90.7	92.1	93.3	95.7	98.2
160	150	94.6	97.1	99.5	102.4	104.8
150	140	101.3	103.9	106.5	109.6	112.5
140	130	109.3	112.3	115.2	118.3	121.2
130	120	124.0	127.1	130.4	133.1	136.0
120	110	133.7	134.6	139.1	140.2	141.5
110	100	142.3	142.8	144.3	---	---
100	90	147.3	---	---	---	---

- -

TIME SAVED OVER CURRENT NAVIGATION CONDITIONS (Hours)

Top-of-Dam Height (meters)	Top of Conservation Pool Elevation (meters)	Bottom of Conservation Pool Relative to Top of Dam (meters)				
		-20	-25	-30	-35	-40
210	200	66.0	65.8	65.5	64.7	63.8
200	190	66.0	65.7	65.4	64.7	63.7
190	180	65.5	64.5	63.5	62.3	61.0
180	170	63.1	61.9	60.4	59.2	57.8
170	160	59.3	57.9	56.7	54.3	51.8
160	150	55.4	52.9	50.5	47.6	45.2
150	140	48.7	46.1	43.5	40.4	37.5
140	130	40.7	37.7	34.8	31.7	28.8
130	120	26.0	22.9	19.6	16.9	14.0
120	110	16.3	15.4	10.9	9.8	8.5
110	100	7.7	7.2	5.7	---	---
100	90	2.7	---	---	---	---

scenarios. This assumption is almost certainly invalid, but literally no information exists on the growth of cargo shipped between these two points in the event that Three Gorge Dam is not constructed. At least two studies are now under way in China, but information is not being disseminated at this time.

(5) if Three Gorge Dam is not constructed, for the basis of comparision, is it assumed that an alternative 830 kilometer long double-line rail route will be built from Yichang to Chongqing at a cost of $1.75 million per linear kilometer of line, and 90 percent of the growing load of cargo will be shipped by rail. The remaining ten percent of the cargo will continue to be barged up the Yangtze in the without-project scenario (DMA).

Step 3: Calculate Navigation Benefits. The final step in this process is the calculation of the alternative cost of transporting the expected volume of cargo in the absence of the Three Gorge project. The total net navigation benefits for the Three Gorge project are the costs of the without-project condition minus the costs of the with-project condition.

Table XXVI is a summary of navigation costs for all Three Gorge reservoir configurations for the four given interest rates. These costs are annualized and consist of two components: fuel costs and estimated operation and maintenance costs.

Since even the lowest dam height or normal reservoir surface elevation would inundate all of the Three Gorges, where the most dangerous and costly navigation in the Yichang-Chongqing reach must occur, the benefits attributed to various dam heights and bottoms of conservation pool elevations differ little if the interest rate is held constant.

TABLE XXVI

ANNUAL THREE GORGE PROJECT NET NAVIGATION BENEFITS

(all benefits in $millions)

Top of Conservation Pool Elevation (meters)	Bottom of Conservation Pool Relative to Top of Dam (meters)					Average
	-20	-25	-30	-35	-40	
Three Percent Interest						
200	82.62	82.55	82.46	82.22	81.95	82
190	82.62	82.53	82.43	82.22	81.92	82
180	82.46	82.16	81.86	81.50	81.11	82
170	81.74	81.38	80.93	80.56	80.14	81
160	80.59	80.17	79.81	79.09	78.33	80
150	79.42	78.66	77.94	77.07	76.34	78
140	77.40	76.61	75.83	74.89	74.02	76
130	74.99	74.08	73.21	72.27	71.40	73
120	70.55	69.62	68.62	67.81	66.93	69
110	67.63	67.35	66.00	65.67	65.27	66
100	65.03	64.88	64.43	---	---	65
90	63.52	---	---	---	---	64
Five Percent Interest						
200	140.62	140.58	140.53	140.38	140.21	140
190	140.62	140.57	140.51	140.38	140.19	140
180	140.52	140.34	140.16	139.94	139.70	140
170	140.08	139.86	139.59	139.36	139.10	139
160	139.38	139.12	138.90	138.46	137.99	139
150	138.66	138.19	137.75	137.22	136.77	138
140	137.42	136.94	136.46	135.88	135.35	136
130	135.94	135.38	134.85	134.27	133.74	135
120	133.22	132.65	132.04	131.54	131.00	132
110	131.43	131.26	130.43	130.22	129.98	131
100	129.84	129.74	129.47	---	---	129
90	128.91	---	---	---	---	129

TABLE XXVI (continued)

ANNUALIZED THREE GORGE PROJECT NAVIGATION BENEFITS

(all benefits in $millions)

Top of Conservation Pool Elevation (meters)	Bottom of Conservation Pool Relative to Top of Dam (meters)					Average
	−20	−25	−30	−35	−40	
Seven Percent Interest						
200	200.11	200.10	200.06	199.97	199.87	200
190	200.11	200.08	200.05	199.97	199.85	200
180	200.05	199.94	199.83	199.70	199.56	200
170	199.79	199.65	199.49	199.35	199.19	199
160	199.36	199.20	199.07	198.80	198.52	199
150	198.93	198.64	198.37	198.05	197.78	198
140	198.17	197.88	197.59	197.24	196.92	198
130	197.28	196.94	196.62	196.27	195.94	197
120	195.63	195.29	194.92	194.61	194.29	195
110	194.55	194.45	193.94	193.82	193.67	194
100	193.58	193.53	193.36	——	——	193
90	193.02	——	——	——	——	193
Nine Percent Interest						
200	259.19	259.18	259.16	259.10	250.03	259
190	259.19	259.17	259.15	259.10	259.02	259
180	259.15	259.08	259.01	258.92	258.83	259
170	258.98	258.89	258.78	258.69	258.58	259
160	258.69	258.59	258.50	258.32	258.13	258
150	258.40	258.21	258.03	257.82	257.63	258
140	257.90	257.70	257.51	257.27	257.06	257
130	257.30	257.07	256.86	257.73	256.40	257
120	256.20	255.97	255.72	255.52	255.30	256
110	255.47	255.40	255.07	254.98	254.89	255
100	254.83	254.79	254.68	——	——	254
90	254.45	——	——	——	——	253

However, once again, the interest rate has the most profound impact of all variables on the benefits under consideration. This is primarily due to the heavy and immediate present-worthed value of the avoided cost of constructing a double-line rail system from Yichang to Chongqing in the without-project transportation system.

The annualized navigation benefits of the Three Gorge project vary only slightly as a function of the top of conservation pool and bottom of conservation pool elevations. In other words, for a given interest rate, there is only about a ten percent variation in navigation benefits regardless of the reservoir configuration selected. This allows an average figure to be given in the right-hand column of Table XXVI for the purpose of simplifying total project net benefit calculations.

This slight variation is due to the fact that, no matter which project configuration is eventually constructed, the hazardous navigation channel through the Three Gorges themselves will be converted to a relatively wide and safe slackwater lake requiring much less fuel to traverse than under current conditions. Additionally, the round-trip fuel requirements for travel on the Yangtze reach between the Gorges and Chongqing are not significantly greater than on a slackwater lake, because river velocity is relatively slow.

CALCULATION OF THREE GORGE PROJECT RECREATION NET BENEFITS

General Principles.

The construction of a dam and reservoir presents an excellent opportunity to develop many different types of water-related recreation

facilities. The presence of a lake will allow such activities as water skiing, boating, fishing, ice skating, and swimming. Recreation activities around the new lake will include hunting, hiking, camping, picnicking, and sightseeing. Although recreation is not a necessary purpose for most large water resource projects, the potential large benefits from such use should not be neglected.

The values of recreational facilities can be derived by estimating the supply costs of providing the facilities and the prices consumers are willing to pay to use the facilities. The cost of providing facilities of various sizes for a specific area can be researched and used to derive a production function (James; Kuiper). Alternatively, the supply costs can be estimated as the opportunity cost of developing an area for other uses. A demand function can be derived indirectly by observing the prices individuals pay to use the facilities, including transportation costs and entry fees. Given the above functions, one can calculate the equilibrium price and quantity. Individuals may not intend to use the facilities, yet desire that they be provided due to neighborhood effects. The value of the recreational facilities to these individuals must be determined with non-market methods (Qayum, 1983).

Recreation Requirements.

Recreation as a reservoir purpose is not wholly compatible with such uses as flood control and navigation. Reservoir operation for recreation would keep a lake at a high, uniform level for as much of the year as possible. Large fluctuations for hydropower and flood

control will damage recreation facilities, expose unsightly mud flats, and render boat ramps unusable.

The ideal recreation shoreline should be shallow in slope to make walking easy, and should be covered with large-grain, clean sand. Recreation facilities commonly have a high ratio of maintenance costs to capital cost, due to the work required in clearing undesirable vegetation, controlling insect pests, and keeping campsites, trails, and beach and picnic facilities clean and available (McGinnis).

Studies have shown that the updated cost of operating and maintaining a set of typical reservoir recreation facilities in the United States is about $0.080 to $0.160 per visitor-day, and average annual amortized capital ranges from $0.070 to $0.280 per visitor-day (Sirles).

The most common types of recreation facilities generally installed at man-made lakes are listed below (James);

* adequately signed access roads;
* parking areas;
* visitor centers and observation points;
* boating facilities, which include boat ramps, docking, fuel and repair services;
* camping facilities, which include tent pads, hookups, showers, vault toilets, picnic tables, fireplaces, waste disposal, and water supply;
* beach facilities, which include floats, separation ropes, bath-houses, and a lifeguard;
* hiking trails, and
* landscaping

Estimating Recreation Usage.

The capacity of a recreation area for boating, camping, swimmming, and picnicking is determined by the available constructed facilites. Capacity for fishing is limited by the number of available fish, and

capacity for sightseeing is essentially unlimited, except in special cases. The water resource planner must provide the best recreation experience to as many people as possible while observing capacity and funding limitations and the impact of the visitors on the surrounding ecology.

The recreational visitation volume at a particular reservoir depends strongly upon the time of year and the area's climate. On a cold winter day, the only users may be a few hardy cross-country skiers, while on a summer Sunday, facilities will be at or near capacity use. In order to design facilities, the planner must know the preferences of the population surrounding the lake; how many persons can be expected to appear at the project on a high-demand day, and what will they want to do?

An analysis of the characteristics of the use of a reservoir must answer the following questions;

* how accessible is the site? The primary factor affecting the usage rate of any site is the travel time and distance from major population centers to the lake. For example, the magnificent Helmcken Falls in Wells Grey Provincial Park, British Columbia, only receives a few thousand visitors each year, due to the remoteness of the Park from large cities.

* what is the demand for outdoor recreation among the surrounding population? This demand will vary with age, income, sex, occupation, and cultural background.

* how attractive is the site for recreation? If several different activities are developed at the same lake, more people will be likely to participate.

* how many other lakes are in the vicinity? If several other lakes are within easy driving distance of major population centers, visitation volume will naturally be smaller.

* how naturally beautiful is the site? The attractiveness of any
recreation site is affected by factors such as mild
climate, rugged and beautiful topography, exotic and
beautiful wildlife, and outstanding historical and cultural
resources.

Estimating Recreation Benefits.

Because of their indirect nature, recreation benefits must be
evaluated by indirect methods. It is impossible to put a dollar value
on a refreshing swim in a lake on a hot summer day, or the spiritual
renewal that a long hike in the wilderness brings. Several methods
have been put forward and used to value recreation benefits, but the
most successful tactic is based on demand curves that are derived from
the expenditures that people incur to enjoy a certain facility. This
cost includes travel to and from the site, and incremental costs (over
the usual at-home costs) for food, lodging, clothing, and equipment
which is required to participate in the activity (James).

Recreation at the Three Gorges.

The Three Gorge area is already a world-famous tourist attraction
which is sometimes referred to as the "Grand Canyon of China."
Currently, about two million visitors travel to the Gorges annually,
despite the lack of local overland trasportation and existing hazardous
navigation conditions. This number included 8,000 foreign tourists in
1979 and 22,200 in 1982 (MWREP, 1983a). The influx of foreign tourists
is expected to grow to 100,000 in 1990 and to 600,000 in 2000. Should
Three Gorge Dam be constructed, about fifty percent of the foreign
visitors who are attracted to the area are expected to visit because of
the dam itself (C3GPDC). The height of the dam or its installed

hydropower capacity will probably have little effect upon the number of foreign visitors who come th China specifically to see the project, since it will be of great interest in any case due to its sheer size (Zhou).

The Three Gorge Dam and Reservoir will render the Gorges much more accessible than a swift, deep river. The possibilities for tourism development are almost limitless. Resorts, hotels, overlooks, and hiking/trekking trails could be built in such a fashion as to be unobtrusive in the wild Gorges. State-sponsored tours of the Gorges and of the dam itself would be great attractions. In fact, current plans show that ten first-class cruise ships will be built specifically for the purpose of conducting foreign tourists on trips up the Three Gorges. The total income to the national government from these ships alone will be about $15 million per year (Xianyi).

If total income to the national economy is assumed to be $250 per foreign visitor, total recreation income due to Three Gorge Dam and Reservoir alone will be about $12.5 million in 1990, growing to about $75 million in 2000 (MWREP, 1983b). If this rate of visitor growth continues for an additional ten years and then levels off, the annualized recreational benefits due to Three Gorge Dam over its lifetime will be about $136 million.

CALCULATING THREE GORGE PROJECT CIVIL WORKS COSTS
Introduction.

This portion of the study is relatively straightforward, because the Chinese government and large engineering companies, including Harza

Engineering, have quantified the costs of constructing the embankment, powerhouse, and navigation locks of several Three Gorge top-of-dam elevations.

The current estimated cost of the 175-meter project was calculated according to China's current regulations, quotas, and fee standards, and used information on actual unit prices confirmed during the construction of Gezhouba Dam.

For the purposes of this study, civil works costs are defined as all project facilities except for the mechanical and electrical equipment associated with generating equipment. The sole exception to this definition is those costs associated with the third powerhouse, which are attached to the separate mechanical-electrical costs for generating units 27 through 31.

Components of the Civil Works Costs.

The civil works costs of the Three Gorge project will include;

* construction of basic project features; embankment, locks, shiplifts, and spillway
* the first and second powerhouses
* construction of support facilities (hospitals, schools, etc.) for 35,000 workers and their families
* 860,000 square meters of living quarters and offices
* 100,000 square meters of warehouses
* detailed geologic exploration
* roller-compacted concrete cofferdams
* construction of access roads and railroads to and around the damsite, as follows;
  * 42 kilometers of special highway from Yichang
  * 42 kilometers of special railway from Yichang
  * 46 kilometers of regular highway around the damsite, and
  * 35 kilometers of regular railway around the damsite.
* nine special docks in the vicinity of the damsite
* land clearing and site preparation
* 40 kilometers of 220 kilovolt transmission lines and 15 kilometers of 110 kilovolt transmission lines with substations for power supply to the construction site. A power peak of 80 megawatts will be required for construction.

* recreation and visitor facilities.

For the purposes of this study, the civil works costs of the Three Gorge project will not include;

* all electrical generating equipment (included in hydropower costs)
* land permanently inundated (included in flood control costs)
* temporary and permanent relocations costs (included in flood control costs)
* transmission line construction to Shanghai, Beijing, and Kuangzhou. The cost of these transmission system additions, to include all transmission lines, substations, and switching stations, is estimated to be approximately $3.7 billion for all project alternatives (MWREP, 1983b). These costs are not included because it is expected that they will be approximately equivalent to the transmission costs of the alternative thermal system.
* the third powerhouse. The costs of units 27 through 31 are dedicated to hydropower (see the hydropower costs section of this chapter).

Assessment of Costs.

Introduction. The costs for two Three Gorge Dam heights have been provided by Harza Engineering and the Ministry of Water Resources and Electric Power. The method used to estimate the costs of other dam heights is described in the following paragraphs.

(1) Estimate Unit Prices. The Ministry of Water Resources and Electric Power has provided construction unit prices, in dollars per unit, as shown below;

Rock excavation (per cubic meter)	6.50
Concrete for main dam (per cubic meter)	33.10
Concrete for powerhouses (per cubic meter)	62.80
Concrete for locks (per cubic meter)	43.00
Transformer and appurtenent electrical equipment (per kilowatt)	45.00
Turbine costs (per ton of finished product)	7,750
Generator costs (per ton of finished product)	7,050

Engineering, design, supervision
and administration (ED&SA)   10%

Embankment costs for a large hydro project in China are usually 60 percent of the total project costs. For the 175 meter Three Gorge Dam alternative, they are estimated by the Chinese government to be 42.6 percent (MWREP, 1983b).

For the purposes of comparison, the closest similar project to the proposed Three Gorge project is Itaipu, on the Parana River between Brazil and Paraguay. Its powerhouses contain eighteen 700 megawatt turbine-generator units which yield an average of 70,000 gigawatt-hours of energy annually. The average annual flow of the Parana River at Itaipu is 8,500 cubic meters per second, and the design head is 118.4 meters. The total project cost in December 1976 dollars was $7.6 billion, including $2.5 billion for interest during construction. Construction took place from January 1976 to February 1983 (Kohne).

(2)   Estimate Concrete Volumes. The most critical single civil works cost item for the Three Gorge Dam is the embankment cost. Given general dam parameters provided by the MWREP and others, embankment concrete volumes for various dam heights are shown in Table XXVII (Clowes, 1987c).

The Three Gorge Dam total length will be 2,330 meters at an elevation of 170 meters. The deepest part of the dam, in the spillway section, will be at an elevation of 10 meters. The crest width, regardless of height, will be 30 meters. The downstream slope of the dam face will be 0.75 horizontal/1.00 vertical, and the total concrete

TABLE XXVII

CONCRETE VOLUMES FOR THREE GORGE PROJECT ALTERNATIVES

Dam Height (meters)	Concrete Volumes (thousand cubic meters)		
	Dam and Spillway	Navigation Facilities	
		Permanent	Temporary
210	23,550	4,265	1,855
200	21,000	3,960	1,720
190	18,635	3,655	1,590
180	16,455	3,350	1,460
170	14,500	3,045	1,325
160	12,595	2,740	1,190
150	10,905	2,435	1,060
140	9,365	2,130	925
130	7,995	1,825	795
120	6,795	1,520	665
110	5,765	1,215	535
100	4,905	910	400

volume for the 170 meter alternative will be 14.5 million cubic meters (USBR, 1984).

For the purposes of comparison, the total concrete volume of the largest existing four projects in the world is as follows (Kohne);

(1) Itaipu - 11 million cubic meters,
(2) Grand Coulee - 8.1 million cubic meters,
(3) Shasta - 6.7 million cubic meters, and
(4) Grand Dixience - 6.0 million cubic meters.

(4) Calculate Final Project Civil Works Costs. Using the parameters, unit prices and volumes derived above, the final estimated costs of various Three Gorge civil works are derived. The costs for the cofferdams, diversion structures, dam and spillway, temporary and permanent navigation facilities, and the right and left powerhouse features are included in these estimates. The results of these calculations are shown in Table XXVIII.

TABLE XXVIII

ANNUALIZED THREE GORGE DAM CIVIL WORKS COSTS

(all costs in $millions)

Dam Ht. (mt.)	Const. Cost	Present-Worthed Civil Works Costs at;							
		3 percent		5 percent		7 percent		9 percent	
		IDC	Total	IDC	Total	IDC	Total	IDC	Total
100	1,207	346	1,553	647	1,854	964	2,171	1,368	2,575
110	1,289	362	1,651	676	1,965	1,014	2,303	1,427	2,716
120	1,371	380	1,751	704	2,075	1,063	2,434	1,505	2,876
130	1,454	397	1,851	731	2,185	1,110	2,564	1,582	3,036
140	1,536	415	1,951	759	2,295	1,165	2,701	1,652	3,188
150	1,628	444	2,072	796	2,424	1,222	2,850	1,729	3,357
160	1,702	450	2,152	824	2,526	1,264	2,966	1,786	3,488
170	1,784	468	2,252	855	2,639	1,310	3,094	1,848	3,632
180	1,867	486	2,353	887	2,754	1,355	3,222	1,914	3,781
190	1,957	505	2,462	920	2,877	1,404	3,361	1,985	3,942
200	2,054	526	2,580	957	3,011	1,456	3,510	2,204	4,258
210	2,197	558	2,755	1,013	3,210	1,539	3,736	2,180	4,377

Dam Height (meters)	Annualized Civil Works Costs at;			
	3%	5%	7%	9%
100	49	93	152	232
110	52	99	161	244
120	55	105	171	259
130	59	110	180	273
140	62	116	189	287
150	66	122	200	302
160	68	127	208	314
170	71	133	217	327
180	74	139	226	340
190	78	145	236	355
200	82	152	246	383
210	87	162	262	394

DERIVATION OF NET THREE GORGE PROJECT ECONOMIC IMPACT CURVE

Introduction.

This section demonstrates how the final total net Three Gorge project economic benefits are converted into a dimensionless impact

curve. The purpose of this exercise is to place economic net benefits into a form that can be combined with the dimensionless social and economic impact curves.

Summing Net Benefits.

To begin with, all Three Gorge project net benefits and costs must be added for each applicable interest rate in order to arrive at total net benefits for each configuration. These items and their sources are shown below;

+ Net flood control benefits	Table XVIII
+ Net hydropower benefits	Table XXIV
+ Net navigation benefits	Table XXVI
+ Net recreation benefits	$136 million
− Civil works costs	Table XXVIII
Total project net benefits	Table XXIX

Table XXIX shows the total net economic benefits of the Three Gorge project at an interest rate of seven percent (net benefits for other interest rates have been calculated, but removed to a separate reference (Clowes, 1987c), so that the text would not become cluttered with long tables.

Assign Proportional Weighting.

Each net benefit in this table is assigned a proportional value based upon an arbitrary maximum amplitude of 10.0. This value may be of any magnitude, since the social and environmental net benefit curves will be assigned scales based upon the maximum amplitude ot the economic benefit curve.

The conversion of the net benefit values to this scale is shown in Table XXX. It is assumed that the base value (in the case of no project construction) is 0.0, and that negative net benefits may lead

to negative values. One of the advantages of this conversion is that the relative net economic benefits between projects becomes easier to compare on a scale of one to ten. This conversion process is another ideal application of spreadsheet programs like Lotus 123.

Effect of Independent Variables Upon Dependent Variables.

As a matter of supplemental interest, Table XXXI shows the relative effects upon project benefits and costs of pertinent independent variables. These independent variables include the interest rate, project installed hydropower capacity, and the elevations of the top of dam and the tops and bottoms of the conservation pools.

Some of these relationships are no surprise. For example, the interest rate affects the amount of interest during construction (IDC) to be charged to all project components quite significantly.

In order for the magnitude of these relationships to be properly verified, the Chinese government or others will have to make use of more detailed and up-to-date information to perform the studies recommended by the author in Chapter VII.

TABLE XXIX

ANNUALIZED THREE GORGE PROJECT TOTAL NET ECONOMIC BENEFITS

(benefits given in $millions)

Seven Percent Interest

Hydropower Installed Capacity (megawatts)		Elevations (meters)					
	TOD --->	100	110	120	130	140	150
	TOCP --->	90	100	110	120	130	140
	BOCP --->	70	80	90	100	110	120
1,000		227	277	286	295	291	276
2,000		250	318	352	407	406	399
3,000		258	327	384	459	470	513
4,000		255	336	406	492	505	597
5,000		248	340	424	513	527	670
6,000		240	343	443	535	550	739
7,000		244	356	473	569	605	811
8,000		249	372	485	604	649	880
9,000		252	386	499	637	690	939
10,000		257	402	509	672	730	989
11,000		256	412	524	698	768	1,034
12,000		255	421	538	726	805	1,080
13,000		255	431	551	754	841	1,136
14,300		257	446	559	788	887	1,200
15,600		260	458	567	824	931	1,262
18,200		271	488	589	900	1,016	1,357
20,800		284	512	601	924	1,094	1,442
23,400		297	532	598	935	1,157	1,519
25,000		307	548	587	931	1,194	1,529
27,000		301	547	588	938	1,211	1,548
29,000		291	539	587	941	1,216	1,559
31,000		279	529	585	942	1,213	1,564

TABLE XXIX (continued)

ANNUALIZED THREE GORGE PROJECT TOTAL NET ECONOMIC BENEFITS

(benefits given in $millions)

Seven Percent Interest (continued)

Hydropower Installed Capacity (megawatts)	Elevations (meters)					
TOD --->	160	170	180	190	200	210
TOCP --->	150	160	170	180	190	200
BOCP --->	130	140	150	160	170	180
1,000	246	211	180	150	67	-67
2,000	370	335	305	273	190	76
3,000	484	452	425	393	309	195
4,000	586	573	546	514	431	317
5,000	667	667	657	630	551	437
6,000	740	748	739	737	662	557
7,000	823	833	821	832	787	712
8,000	895	917	909	921	880	824
9,000	963	990	989	1,008	967	909
10,000	1,029	1,062	1,059	1,089	1,055	984
11,000	1,074	1,118	1,120	1,150	1,123	1,057
12,000	1,119	1,163	1,174	1,204	1,177	1,138
13,000	1,164	1,212	1,228	1,259	1,245	1,191
14,300	1,225	1,283	1,288	1,331	1,305	1,262
15,600	1,274	1,359	1,349	1,396	1,379	1,339
18,200	1,378	1,473	1,473	1,528	1,521	1,490
20,800	1,471	1,572	1,579	1,642	1,641	1,618
23,400	1,553	1,660	1,672	1,740	1,745	1,727
25,000	1,569	1,714	1,729	1,800	1,807	1,792
27,000	1,594	1,745	1,770	1,847	1,857	1,843
29,000	1,615	1,763	1,790	1,873	1,884	1,874
31,000	1,622	1,772	1,796	1,887	1,894	1,887

TABLE XXX

EXAMPLE: ANNUALIZED THREE GORGE PROJECT NET ECONOMIC IMPACT MAGNITUDE

Seven Percent Interest
Top of Conservation Pool Elevation Ten Meters Below Top of Dam
Bottom of Conservation Pool Elevation Thirty Meters Below Top of Dam

(Scale: 0.0 to 10.0)

Hydropower Installed Capacity (megawatts)		Elevations (meters)					
	TOD ―>	100	110	120	130	140	150
	TOCP ―>	90	100	110	120	130	140
	BOCP ―>	70	80	90	100	110	120
1,000		1.20	1.46	1.51	1.56	1.54	1.46
2,000		1.32	1.68	1.86	2.15	2.14	2.11
3,000		1.36	1.73	2.03	2.42	2.48	2.71
4,000		1.35	1.77	2.14	2.60	2.67	3.15
5,000		1.31	1.80	2.24	2.71	2.78	3.54
6,000		1.27	1.81	2.34	2.83	2.90	3.90
7,000		1.29	1.88	2.50	3.00	3.19	4.28
8,000		1.32	1.96	2.56	3.19	3.43	4.65
9,000		1.33	2.04	2.64	3.36	3.64	4.96
10,000		1.36	2.12	2.69	3.55	3.85	5.22
11,000		1.35	2.18	2.77	3.69	4.06	5.46
12,000		1.35	2.22	2.84	3.83	4.25	5.70
13,000		1.35	2.28	2.91	3.98	4.44	6.00
14,300		1.35	2.36	2.95	4.16	4.68	6.34
15,600		1.37	2.42	2.99	4.35	4.92	6.67
18,200		1.43	2.58	3.11	4.75	5.36	7.17
20,800		1.50	2.70	3.17	4.88	5.78	7.61
23,400		1.57	2.81	3.16	4.94	6.11	8.02
25,000		1.62	2.89	3.10	4.92	6.30	8.07
27,000		1.59	2.89	3.11	4.95	6.39	8.17
29,000		1.54	2.85	3.10	4.97	6.42	8.23
31,000		1.47	2.79	3.09	4.97	6.40	8.26

The maximum annual benefits shown for any studied Three Gorge Reservoir configuration at seven percent is $1,894 million for an installed hydropower capacity of 31,000 megawatts at a top of conservation pool elevation of 200 meters. This net benefit is assigned a value of 10.0, and all other values are set proportional to this.

TABLE XXX (continued)

EXAMPLE: ANNUALIZED THREE GORGE PROJECT NET ECONOMIC IMPACT MAGNITUDE

Seven Percent Interest
Top of Conservation Pool Elevation Ten Meters Below Top of Dam
Bottom of Conservation Pool Elevation Thirty Meters Below Top of Dam

(Scale: 0.0 to 10.0)

Hydropower Installed Capacity (megawatts)	TOD --> TOCP --> BOCP -->	Elevations (meters)					
		160 150 130	170 160 140	180 170 150	190 180 160	200 190 170	210 200 180
1,000		1.30	1.11	0.95	0.79	0.35	-0.35
2,000		1.95	1.77	1.61	1.44	1.00	0.40
3,000		2.56	2.39	2.24	2.08	1.63	1.03
4,000		3.09	3.03	2.88	2.71	2.28	1.67
5,000		3.52	3.52	3.47	3.33	2.91	2.31
6,000		3.91	3.95	3.90	3.89	3.50	2.94
7,000		4.35	4.40	4.34	4.39	4.16	3.76
8,000		4.73	4.84	4.80	4.86	4.65	4.35
9,000		5.08	5.23	5.22	5.32	5.11	4.80
10,000		5.43	5.61	5.59	5.75	5.57	5.20
11,000		5.67	5.90	5.91	6.07	5.93	5.58
12,000		5.91	6.14	6.20	6.36	6.21	6.01
13,000		6.15	6.40	6.48	6.65	6.57	6.29
14,300		6.47	6.77	6.80	7.03	6.89	6.67
15,600		6.73	7.18	7.12	7.37	7.28	7.07
18,200		7.28	7.78	7.78	8.07	8.03	7.87
20,800		7.77	8.30	8.34	8.67	8.66	8.54
23,400		8.20	8.77	8.83	9.19	9.21	9.12
25,000		8.28	9.05	9.13	9.50	9.54	9.46
27,000		8.42	9.21	9.35	9.75	9.81	9.73
29,000		8.53	9.31	9.45	9.89	9.95	9.89
31,000		8.56	9.36	9.48	9.96	10.00	9.96

TABLE XXXI

RELATIVE DEGREE OF IMPACT:
INDEPENDENT VARIABLES UPON DEPENDENT VARIABLES

Dependent Variables	Independent Variables				
	Elevations			Hydropower	
	Top of Dam	Conservation Pool		Installed Capacity	Interest Rate
		Top	Bottom		
Benefits					
Flood control	large	none	slight	none	large
Hydropower	none	moderate	slight	moderate	large
Navigation	minor	minor	minor	none	large
Recreation	none	none	none	none	none
Costs					
Mech/Elect	none	none	none	large	minor
Civil Works	slight	none	none	none	large
Total Net Benefits					
	moderate	slight	slight	slight	large

Explanation of the relative magnitude of terms;

Minor. The stated dependent variables are sensitive to the stated independent variable (all other independent variables held equal) to such a degree that the largest value of the dependent variable among all studied project configurations will be no more than ten percent greater than its smallest value.

Slight. Definition as above; variation in dependent variable between ten percent and fifty percent.

Moderate. Definition as above; variation in dependent variable between fifty percent and one hundred percent.

Large. Definition as above; variation in dependent variable greater than one hundred percent.

CHAPTER V

EVALUATION OF NET THREE GORGE PROJECT SOCIAL IMPACTS

STANDARD OF LIVING VS. QUALITY OF LIFE

Introduction.

The terms 'quality of life' and 'standard of living' are used interchangeably by many agencies and individuals. However, it is important to make a distinction here, because their relationship is tenuous at best, and may vary depending upon a country's degree of development. The concept of 'standard of living' addresses the question of what one <u>has</u> or consumes, while 'quality of life' deals more with what one can expect to <u>get</u>; that is, his galaxy of aspirations and expectations. Obviously, if there was a direct correlation between the two terms, all rich persons would be happy, and all poor persons would be miserable.

'Quality of life' may be tied more closely to 'standard of living' in underdeveloped countries. The people are primarily concerned with obtaining their most basic needs: food, potable water, and shelter. This may generally be more or less their accepted lot in life, and aspirations and expectations may be quite low. After the basics are made generally available, the people concern themselves with pursuing higher-order needs. In developed countries, 'quality of life' no longer has such a close tie to 'standard of living.'

The Measurement of Standard of Living.

Standard of living criteria generally deal with the wages and level of consumption of the populace. However, even these seemingly concrete terms are only relative, and extreme care must be taken whan assessing standard of living criteria in developing countries. The pitfalls are numerous, and personal misconceptions and inconsistencies in economic terms and conversions may play a large role in misinterpretations.

For example, the per capita gross national product of the United States is roughly $5,000 per year, and that of China about one-tenth of this amount. Wages generally range from about 25 yuan per month for a Shanghai shoe cleaner to 600 yuan per month for the Minister of Communications. At the current exchange rate, these wages would be equivalent to about US $100 to US $2,500 annually (Howe, Christopher). These raw figures might lead one to assume that the Chinese have a very low standard of living. However, they must not be used to assess the standard of living of the Chinese populace.

The official exchange rate vastly underestimates the purchasing power of the yuan in China, perhaps by a full order of magnitude. The Minister who lives in relative opulence in Wuhan could not possibly survive on $2,500 per year here in the United States. Additionally, changes in the GNP indicators may not be of much use. Even though GNP per capita in China has been rising steadily lately, much of this increase is due to accelerated growth in heavy industry, a trend which will not proportionally increase the average peasant's standard of living. Still, in China, once known as "the sick man of Asia," the

standard of living has been increasing steadily over the past fifteen years as personal consumption of such items as cotton cloth, bicycles, living space, and calories of food have increased.

The measurement of Chinese standard of living as a whole is exceptionally difficult, primarily due to the paucity of useful data which has emerged from the country in the last three decades. Additionally, consumption patterns and quantities differ radically between urban and rural dweller, and even among communes, brigades, and teams.

The Measurement of Quality of Life.

Overview. While the measurement of standard of living is based chiefly upon the measurement of lower-order needs, 'quality of life' is based more upon perceived needs.

The process of accurately measuring the fulfillment of lower-order needs that relate to 'standard of living' can be tedious, but is relatively simple in comparison to the measurement of the fulfillment of higher-order needs. For instance, the provision of potable water to a group of villages may be quantified quite readily in terms of percentage of persons served, and the resulting avoidance of disease and fatiguing labor.

Meanwhile, 'quality of life' is measured in terms of such nebulous concepts as a "general sense of well-being," "happiness," or "satisfaction." These vague definitions, in order to be useful, must be based upon the measurement of concrete criteria such as race, age, sex, marital and employment status, and perceptions of personal competence.

The difficult task of quantifying 'quality of life' has bedeviled social scientists for more than half a century (Campbell). The use of such terms incurs two inevitable basic difficulties, described as follows.

Examiner bias. In order to force the concept of 'quality of life' into tangible terms, it is necessary to use one or more of a variety of methods to define intangibles in tangible terms for the purpose of the required interviews. This conversion process will inevitably introduce the biases of the measurer. Much of this distortion is due to the language of the examiner, which prevents the right questions from being asked and the right answers from being received. As Nietzsche said, "Jedes Wort ist ein Vorurteil" - every word is a prejudice.

The background of the examiner is a critical source of distortion, as well. How can even an experienced Western-educated sociologist possibly make the huge leap from assessing impacts in the United States or Europe to performing the same task in a developing country? Most of his training will be useless or worse than useless - it will be a detriment, and he may need months or years to unlearn many of the procedures and models that he has incorporated into his work routine.

The only solution to this problem may be to train a group of persons from the area of the proposed projects. These persons could be those with some standing and knowledge of the community, i.e., Provincial council members, or Brigade officials. They could serve as an information source and interviewers for the study team. Their training should certainly be held to a minimum, since it would inevitably introduce the biases that the study team would like to

avoid. Of course, the results would still be subject to the study manager's misinterpretations.

Subject bias. Statistical methods are powerful tools, but there is no way they can account for the vast psychological and social differences between interviewees. An intolerable situation to one person may be perfectly satisfactory to another, who perhaps is resigned to his fate. This 'satisficing' may lead to artificially inflated ratings. Every person has a different value system and set of standards, which are products of his totally unique personality and experience of life.

In the United States, rapid, and sometimes violent, social change is often prized as beneficial to the country as a whole. In China, this may not be the case. For example, relocations in the United States involve moving persons who may not have very deep roots in the area, and who are generally satisfied if they are moved into an area of equal or greater value. However, relocations in China may cause great tension and lifestyle disruption, since the same families have been in the area for centuries. The changes wrought by relocations have far more severe impact than changes in a society left alone. In other words, relocations have effects that are 'revolutionary, not evolutionary' (Milsum).

Of course, the most basic question involves the government's attitude towards the 'quality of life' of the populace in the first place. It seems that the underlying motive of much activity in the United States is to improve one's collections of 'things' or to expand the horizons of personal expectations, and this attitude is reflected

in the actions of government at all levels. In China, of course, the situation is far different. The government strives to provide the "Five Guarantees" - a job, an education, health care, a place to live, and proper burial. However, personal values tend to be submerged for the good of the whole, and 'quality of life' may not even enter into the equation, unless the effects of a project include obvious negative impacts on production.

The decisionmaker may wish to assign his own monetary value to the total positive or negative 'quality of life' impacts of the project, thus adding it to the tangible benefits and costs. Alternatively, he may wish to keep the indicator separate and base his decision on two variables. The following paragraphs describe examples of the magnitude of profound, extensive, and significant project impacts.

WATER RESOURCE PROJECT SOCIAL IMPACTS

Overview.

The sociological impacts of dam and reservoir construction can profoundly disrupt the way of life of small or powerless groups of people. The following paragraphs describe two of the ways in which the construction and operation of a large water resource project in a developing country may adversely affect the quality of life of tribes, villages, and individuals.

Disease.

Irrigation and impoundment schemes may bear a heavy social cost in certain tropical and semitropical areas by enhancing or creating conditions favorable for the breeding of waterborne parasites and the diseases they carry, such as schistosomiasis, malaria, dengue fever,

and eosinophilic meningitis. In some areas heavily infected by schistosomiasis, life expectancy is only 26 years. In four major studies, the incidence rate of schistosimiasis multiplied up to 37 times after large irrigation schemes were constructed (Biswas, 1980). Following the Volta Reservoir impoundment, the incidence of schistosimiasis increased from 2 to 82 percent (Goodland). Table XXXII lists some of the diseases that may be introduced or whose incidence may be increased by the construction of an impoundment or irrigation system in a developing country.

Relocation-Induced Shock.

Certain cultures maintain such strong ties to their homelands that compelled relocation is tantamount to a death sentence for the weaker members of the community. Some members of tribes relocated to make way for the Nanr Pung Reservoir in Thailand died of progressive traumatic shock (LaBounty). If relocations require that persons be transferred great distances, the exchange of diseases may decimate the weak. The intimate value of the land to those that have dwwelled upon it all of their lives is eloquently summarized by a Guyanese Akawaio Indian;

> This land is where we belong - it is God's gift to us and has made us as we are. This land is where we are at home, we know its way: and the things that happen here are known and remembered, so that the stories the old people told are still alive here. This land is needed for those who come after us. This land is the place where we know where to find all that it probides for us - food for hunting and fishing, and farms, building and tool materials, medicines. Also the spirits around us are friendly and helpful. This land keeps us together within its mountains - we come to understand that we are not just a few people or separate villages, but one people belonging to a homeland. If we had to move, we would be lost to those

TABLE XXXII

SELECTED CASES; PESTS INTRODUCED OR INCREASED BY
CONSTRUCTION OF RESERVOIRS OR IRRIGATION SYSTEMS

Human Diseases

Disease	Parasite or Carrier	Project	Area
Malaria	Anopholes Gambiae Anopholes Funestas Plasmodium Vivax Plasmodium Falciparum	Irrigation Mahaweli Dam Irrigation	Africa Sri Lanka South Asia
Visceral, Urinary, and Intestinal Schistosomiasis	S. Mansoni S. Haematobium S. Japonicum	Irrigation High Aswan Irrigation	South Africa Egypt Asia
Filariasis (Elephantiasis)	Wucheria Bancrofti (a mosquito parasite)	Irrigation	SE Asia
Onchocerciasis (River Blindness)	Oncheocerus Volvulus (Blackfly host)	Irrigation	Volta River
Sleeping Sickness	Tsetse Fly	Kariba Dam	Zambia

- -

Plant Diseases

Common Name	Parasite or Carrier Scientific Name	Target	Area
Great Moth	Polychrosis Botrana	Cotton	Egypt
Cotton-Leaf Worm (Spodoptera Moth)	Spodoptera Littoralis	Peanuts, Sugar Beets	Egypt
Oriental Corn Borer (Corn Stalk Borer)	Chilo Agamemnon	Corn	Egypt
Onion Fly	Hylemyia Antiqua	Corn	Israel
Seed Corn Maggot	Hylemyia Cilicrura	Corn	Israel
Red Pumpkin Beetle	Rhaphidopalpa Foreicollis	Cucurbit	Israel
Weevil	Hypera Variabilis	Alfalfa	Asia, America
Spiny Boll-Worm	Earias Insulana	Cotton	Israel

References; Graham; Lavergne; Dogra; Biswas, 1980; Bandyopadhyay;
      Colchester.

who remain in other villages. This would be a sadness
to us all, like the sadness of death. Those who moved
would be strangers to the people and spirits and places
where they are made to go.

— Statement of the Akawaio Indians
Guyana, 1977

Unfortunately, studies showing that even numerous deaths may occur
as a direct or indirect result of a project may be ignored or
'modified' due to their political sensitivity.

Summary.

Although it is far simpler to quantify short-term changes in
'quality of life' than it is to measure such a parameter in its
absolute and relatively static state, problems do remain. However,
this is no excuse for ignoring project impacts on 'quality of life,'
for this is indeed, as Yankelovich has stated, 'suicide' — perhaps for
an unstable government in a developing country.

A METHOD FOR QUANTIFYING WATER RESOURCE PROJECT IMPACTS ON QUALITY OF LIFE

Overview.

Although it is physically impossible to measure the changes in
'quality of life' brought about by the construction and operation of a
large water resource project, it may be helpful to decisionmakers to
have at hand a few simple descriptive words that can at least give some
indication of the magnitude of possible impacts. This is vitally
important, particularly in developing countries. Aside from the
obvious difficulties in applying such devices as Cantril's
"self-anchoring striving scale," the expertise and motivation to do so

may be nonexistent. Finally, even if a set of numbers is produced, they may have little or no meaning to persons with a strongly technical background.

This chapter outlines a simple method for measuring short-term 'quality of life' changes in terms of profound, extensive, and significant positive and negative impacts. Although this method has many drawbacks as stated in the text, it can be adapted and applied in a social cost-benefit analysis for the purpose of approximating total project impacts.

Supporting information on the effects of Three Gorge outputs in the form of relocations and hydropower, irrigation, flood control, and navigation benefits on 'quality of life' is sadly lacking. Additionally, the proper assessment of the impacts of these outputs would require the attentions of a trained team of indigenous sociologist for a period of several years. and is far beyond the scope of a dissertation.

The use of words with some emotional and descriptive content may have more of an effect towards insuring that the actual sociological costs of relocations are properly assessed. For example, the sentence "impacts upon the society of the 17,000 persons of the Datonka Tribes will be profound," followed by a list of specific impacts, states a truth that cannot be avoided, explained away, or swept under the rug. On the other hand, the statement "relocating the 17,000 persons of the Datonka Tribes will cost the government approximately $9 million" is devoid of feeling, and renders the people just another line in the final cost estimate.

It is obvious, however, that the application of even these most rudimentary descriptive devices is fraught with difficulties, not the least of which is the quality of information that the study managers use to produce the words that describe the magnitude of project impacts. All of the problems associated with the assignment of raw numbers to 'quality of life' issues are reproduced here, but only on a less acute level.

Descriptive words for a water resources study might be "profound," "extensive," and "significant," as outlined in the following paragraphs. Figure 8 shows the relative position of these impacts on a dimensionless linear scale.

Profound Impacts.

A profound impact might be defined as the highest-order benefit or cost that a large water resource project could confer upon a group or an individual. In such a case, the construction and operation of a project would either extend or shorten lives significantly, or lead to the most extreme increase or decrease in 'quality of life,' as defined by the culture, not the study team or decisionmaker. The project might fulfill many of the basic needs of a poor populace (lighting, powered irrigation, fish), and therefore would allow them to pursue higher-order needs. Alternatively, a project might have a severely detrimental impact on a group with little political power or voice.

Hundreds of large water resource projects have shortened or extended many lives, generally in less-developed areas. However, the construction of a reservoir by itself will not guarantee that lives will not be lost. Planning and construction must go hand-in-hand with

Scale	Magnitude of Project Impact

```
|      /|\          <--|--> Profound impact                    |
|       |           <--|                                       |
|   BENEFICIAL      <--|--> Extensive impact                   |
|  PROJECT IMPACT      |                                       |
|       |           <--|--> Significant impact                 |
|      \|/             |                                       |
|_____   <--|--> Little or no impact  _____|
|      /|\             |                                       |
|       |           <--|--> Significant impact                 |
|    HARMFUL           |                                       |
|  PROJECT IMPACT   <--|--> Extensive impact                   |
|       |              |                                       |
|      \|/          <--|--> Profound impact                    |
```

Figure 8. A dimensionless linear scale defining the relative magnitude of water resource project impact upon quality of life.

a carefully executed program of relocations and attention to the actual and perceived needs of the area's people.

The assignment of "profound impacts" to a project might mean, in some cases, that the value of a human life must be assessed. While there is generally no need to place a value on human life when it is apparent that a project will only extend lives, thorny questions arise relentlessly if there is the possibility that a project will take or shorten lives. The task of assigning a monetary value to that most precious of commodities, a human life, is intractable indeed. Should all human lives be considered equally valuable, despite differences in social status, income, age and health? If not, how will one quantify these differences and assign values to person-years? Should the

measure of worth be a person's potential contribution to society?

There is great, if distant, danger in this valuation of the ultimate intangible. Perhaps inevitably, the problem has been met head-on by what some may consider to be the most extreme abuse of a purely technological viewpoint. The United States is the world leader in concocting mathematical formulae which are, in reality, benefit-cost analyses that determine the worth of a human life. For example, during hearings regarding the widely publicized tendency of Pintos to explode upon being rear-ended, study papers revealed that the Ford company had assigned a value of $200,000 to a human life when deciding whether or not to make design changes in the car (Reilly). These calculations are usually not based upon firm or reproducible data, but instead on an individual's perceived potential contributions to society. This value may vary widely, of course, with factors such as the education, race, sex, and prejudices of both the subject and the study manager.

Such criteria have been seriously proposed (and, in rare cases, applied) in Europe and the United States to handicapped infants and the frail elderly for the purpose of rationing scarce medical resources. Although no widespread trend is evident, the concept of assigning a naked dollar value to a human life, with no other criteria to temper a decision, is profoundly troublesome to many.

Although a project may have severe unforeseen impacts on a segment of the populace, it is illogical to suspend the construction of large projects because of possible fatalities. Although the valuing of a human life is a sensitive issue, and although we like to say that a human life has infinite worth, our everyday actions indicate other-

wise. We participate in activities every day which have a low probability but high consequence: traveling, smoking, eating fatty foods, and other such actions.

Extensive Impacts.

An extensive impact would be of a lesser order than a profound impact, but its effects could be widespread on a national level, or would cause a radical change in the 'quality of life' of smaller groups of individuals. One possible beneficial 'extensive' impact in a developing country could be rural electrification, which would light the homes of the peasants and relieve them of the backbreaking toil in carrying washing and irrigation water by hand. However, the impacts of a project might be negative in nature, as well, such as the introduction of debilitating diseases.

Significant Impacts.

A significant impact might be defined as a noticable change in the 'quality of life' of individuals or groups, which was directly brought about by the construction of a large water resource project. It would be beyond the scope of minor irritations and inconveniences caused by relocating, and might include, for example, isolation or 'shunning' by neighbors in the new community, or difficulties encountered in the learning of a new job or trade. On the positive side, it might involve increased recreational opportunities or easier catches of fish.

CASE STUDIES

The Value of Case Studies.

By making use of hindsight and by studying the injurious impacts of existing projects, study teams may be better prepared to properly

apply descriptive language to the project which they are considering. In any case, the greatest value of case studies is the inculcation into study teams of a perspective other than their own. In the author's opinion, works such as Goldsmith's The Social and Environmental Effects of Large Dams should be mandatory reading for every person who works on the planning and design of any water resource project.

The following paragraphs describe some of the most obvious negative sociological and environmental impacts brought about by the construction and operation of four large water resource projects in developing countries on the African and South American continents. It would be incumbent upon the reader to decide which impacts are "profound," "extensive," and "significant," using his own experiences as a guide.

Akosombo Dam.

The Akosombo Dam straddles the Volta River near the town of Akosombo, Ghana. In conjunction with this project, the Ghanaian government hired the Henry J. Kaiser Corporation of the United States to construct homes for 80,000 families who would be relocated from their mud huts in order to make way for the new reservoir.

To the government of Ghana, which has placed great emphasis on modernization and the raising of the standard of living of its citizens, this move might have been perceived as having a highly beneficial impact on the people, because it would certainly greatly raise their standard of living — but only by a city-dweller's terms. Because of a conflict between the Ghanaian government's organizational perspective and the personal or sociological perspective of the people,

this relocation had exactly the opposite effect of that desired.

This project has given us a classic example of how an ingrown national government lost its perspective and efficiently but unjustly condemned an entire culture in the name of progress. The guiding principle of this myopic worldview is neatly summarized by A. Kalitsi (1970);

> At other times, however, as a result of national policy, it becomes necessary for people to move in order to make room for a development which will benefit not themselves individually as such, but society as a whole.

The process began with the reclassification of certain tribes from a "national treasure" to "subsistence farmers" who represented a "backward and primitive" way of life. The land which had so generously provided for the needs of the people for many generations suddenly became "unsuitable for agriculture" (Graham).

During the forcible and abrupt relocation effort itself, 740 small settlements of greatly diverse ethnic background were "homogenized" and placed into 52 new and larger settlements (Biswas, 1980). This caused extreme friction among the tribespeople, because old friendships and stable adverserial relationships were suddenly shattered, leading to a tremendous amount of individual and tribal instability.

Nor did the government keep all of its promises regarding new facilities. The twelve acres promised to each farmer shrank eventually to two as the government's inefficient and inertia-ridden bureaucracy struggled to clear new land. Many of those relocated by the government were miserable in their new quarters, because the transition from mud hut to modern home was just too abrupt and extreme.

Families would typically tear the front door of their home from its hinges because they were unused to carrying keys. Fishermen kept their boats inside the homes, causing extensive damage to fixtures, and families would cook in pit fires located in the living rooms. Since the tribespeople were unused to bathing in enamel tubs, many suffered severe injuries from slipping, and numerous infants were scalded in water that was far too hot for them. The outside cubical toilets were abandoned in favor of open trenches which allowed face to face conversation (Barnor).

The government also overlooked the fact that the tribespeople were traditionally polygamous. Their old homes consisted of central room for the husband with a smaller attached cubicle for each wife. The housing provided by the government consisted of a concrete structure with one spacious room. This eliminated all privacy for family members. The government took the position that the occupants could always add rooms to the houses if they so desired, but neglected to consider the fact that the cost of building materials was far beyond the villager's means.

The historically healthy tribespeople fell prey to endemic diseases in their new locale. The incidence of malaria and river blindness increased over fifty percent, and the schistosomiasis infection rate increased from only three percent to more than eighty percent (Graham).

Eventually, a large percentage of the relocated people abandoned the heavily damaged homes and moved back into mud-thatched huts by the

river, leaving the government holding more than a billion dollars worth of unoccupied and deteriorating homes.

Kariba Dam.

The 130-meter high Kariba Dam, completed in 1960, impounds the Zambesi River and the world's fourth-largest reservoir, at 160 cubic kilometers total capacity. This reservoir lies along the Zimbabwe/Zambia border (formerly North and South Rhodesia), and the 1,500 megawatt powerhouse serves the region's growing copper industry (Cullen).

Before the reservoir was filled, about 50,000 persons had to be relocated to areas 25 to 150 kilometers away from their traditional lands. Relocated persons included the Batonka tribe, considered by the Rhodesian governments to be living under the most primitive of conditions. The Batonka were moved from the river valley's rich alluvial soil to a drier area with thin, dusty topsoil. Although these people might have suffered great hardships because of the transfer, the government anticipated the situation and supplied the tribe with rations, fertilizer and the tools necessary to survive the transition and make the new land productive.

The Batonka at one time were prey to numerous diseases and disabilities, including leprosy, hookworm, schistosomiasis, malaria, dysentery, yaws, and sleeping sickness. A 100-bed clinic with a specially-trained staff was built at Binga specifically for the purpose of eradicating these afflictions.

The provision of this health care may very well have added years to the life of the average Batonka tribesman. However, it is entirely

possible for a single project to extend the lives of some groups of people while cutting short the lives of others. Such is the case with Kariba. Although the governments of North and South Rhodesia showed great foresight in caring for some of the Batonka, they did not fully anticipate existing and latent political forces which led to the deaths of others.

The African National Congress, strongly opposed to the dam from the beginning, alleged that the river god Nyaminyami did not want the dam built. As proof, the ANC pointed to the extreme difficulties encountered by the work crews during construction. On consecutive years, 1,000 and 10,000 year floods inundated the project's cofferdams. This 'proof' persuaded about six thousand of the Gwembe District Batonka to resist relocation. Eight tribesmen were shot or clubbed to death in the ensuing struggle with government troops (Clements).

The Aswan High Dam.

This project, completed in 1968, is a classic example of how a benefit-cost analysis can neglect or underestimate the diverse environmental and sociological impacts of project construction on a wide segment of a country's population. Although the Aswan High Dam has always been strongly portrayed as beneficial to Egypt, exhortations by the government and 'experts' are small comfort to the relatively small segment of the population that has borne its negative impacts.

Lake Nassar is one of the largest man-made lakes in the world. It contains 162 cubic kilometers of storage and possesses 5,000 square kilometers of surface area. The project's powerplants, which house

2,400 megawatts of installed hydropower capacity, produce about ten terawatt-hours of energy annually. Lake Nassar opened up 417,000 acres of land to irrigation, and the government simultaneously upgraded the irrigation systems of 375,000 additional hectares (Biswas, 1983).

The turbid Nile waters have historically transported large quantities of nutrients to the lower reaches of the River before the High Aswan Dam was built. After dam closure, the deposition rate of silt on downstream lands dropped dramatically. It is estimated that, in the last two decades, more than two billion tons of sediment has been trapped by Lake Nassar. This volume of silt is equivalent to a layer one meter thick over an area of 675 square kilometers.

This lack of sediment has caused the river's delta to retreat inland as much as two kilometers. Saltwater intrusion into the delta, which is 1,000 kilometers downstream of the High Aswan Dam, has rendered river water useless for irrigation, and agricultural production in the delta has dropped steeply. This has forced may farming families out of the area to other occupations, which are partially subsidized by the government.

Since most of the silts of the Nile now languish at the bottom of Lake Nassar, most of the river's nutrients fail to reach land downstream of the dam. In the decade after the project was completed, national nitrogenous fertilizer consumption doubled to 1.2 million tons per year, and annual phosphate use jumped from 92,000 tons to 322,000 tons. Incremental fertilizer costs are now in excess of $100 million per year (Lavergne).

Additionally, the relatively 'clean' water has led to a drop in plankton and organic carbon travelling downstream, which has caused a 90% drop in the commercial sardine and crustacean catch in the eastern Mediterranean area (Biswas, 1979). Fortunately, Lake Nassar is a rich fish breeding ground, yielding some 20,000 tons per year. Some of the fishermen who had lost their jobs on the Sea due to reduced catches have managed to relocate to the lake itself.

Finally, Lake Nassar possesses a surface area of more than 5,000 square kilometers. This enormous area, exposed to hot and dry climatic conditions, leads to an average annual evaporation loss of 475 cubic meters per second (16,800 cubic feet per second), enough water to irrigate more than 800,000 hectares. This evaporation rate can be increased by as much as 25 percent by steady winds.

Despite these unforseen impacts, High Aswan Dam hydropower, flood control, and irrigation benefits made the payback period of the project slightly more than two years, an extraordinarily short time. Although the project was a critical factor in Egypt's economic development, secondary impacts could have been foreseen and compensated before construction. The impacts on certain fishermen and farmers were only noticed after project construction, and their 'quality of life' was decreased significantly while they made the transition to their new jobs.

Balbina Dam.

Some of the adverse sociological and environmental impacts of large projects may be so diffuse that the debate over their valuation may never be settled. These worldwide effects usually fall under the

category described in Hardin's "Tragedy of the Commons." Balbina Dam in Brazil is an excellent example.

The project is currently under construction on a tributary of the Amazon River, about 160 kilometers north of Manaus. The primary purpose of the project is to produce 250 megawatts of dependable hydropower to the region's expanding economy. However, the planned lake will cover an area of 2,200 square kilometers, making it one of the largest impoundments on earth. Critics charge that flooding such a large area of irreplaceable rain forest is irresponsibility of the grossest kind, and that the planners of the project have disregarded the huge environmental impact that such a plan will have.

On paper, the benefit-cost ratio of the project looks very good indeed, but only because the economic value of the surrounding rainforest is considered to be negligible. However, the obvious potential adverse consequences to global ecology are almost limitless, in terms of lost botanical and animal resources.

DERIVATION OF A DIMENSIONLESS SOCIAL IMPACT CURVE FOR THE THREE GORGE PROJECT

Introduction.

The purpose of this section is to describe a procedure for constructing a dimensionless sociologic impact curve for the purposes of assisting the decisionmaking process. This curve is the second of three that will be used to detemine the most favorable range of Three Gorge project alternatives that may be selected when economic, social, and environmental considerations are all taken into account.

Determining the Shape of the Social Impact Curve.

Introduction. In order to determine the shape of the sociological impact curve, some numbering system must be used in order to define the relative impact of positive and negative project impacts. This process does not require the assignment of a monetary value to any impact or groups of impacts; it merely deals with the relative impacts within the class of social consequences.

For the purposes of this study, the following descriptive words and relative weights are used to determine the shape of the social impact curve. Despite efforts to conform these weights and classifications to what is perceived to be the Chinese value system, they are necessarily, at least in part, a product of the author's background, experiences, and biases. Table XXXIII includes these classifications and weights and should serve as an example only. If an indigenous study team and the affected populace generate this table, it will have a much greater degree of validity.

The major impact categories that are considered for Three Gorge Dam and Reservoir are lives saved by project flood control operations, permanent relocations, temporary upstream and downstream relocations, and farmland and rural dwellings protected by project flood control operations. These figures are given in Chapter IV and in other references (Clowes, 1987c; MWREP, 1983b).

Lives Saved by the Three Gorge Dam. Under current conditions, an average of about 5,000 lives are lost annually to the Yangtze in its middle and lower reaches. The vast majority of this number occur during very large (100-year and greater) flood events. Most of the

TABLE XXXIII

RELATIVE MAGNITUDE OF POSITIVE AND NEGATIVE PROJECT SOCIAL IMPACTS

(all impacts refer to the social effects upon one person)

Descriptive Language	Relative Weight	Type of Impact
Lifesaving	+15	Project flood control operations save a life
Profound Beneficial	+3	Eradication of debilitating disease Power to eliminate hand irrigation Provision of potable water
Extensive Beneficial	+2	Simplified navigation Higher crop yield due to project-supplied irrigation water
Significant Beneficial	+1	Prevention of temporary relocation due to project flood control operations Prevention of farmland inundation
Significant Harmful	-1	Temporary relocation caused by project flood control operations; minor damage to crops, housing, and contents
Extensive Harmful	-2	Extensive damage to housing and contents caused by project flood control operations Permanent relocation to an appropriate social environment to make way for project reservoir filling Waterlogging/salinization of land
Profound Harmful	-3	Permanent relocation to an inappropriate social environment to make way for project reservoir filling Introduction or aggravation of incidence of debilitating disease
Life-Ending	-15	Fatality caused directly or indirectly by project construction or operations; disease introduction, on-site job fatality, forced relocation trauma, civil unrest caused by relocation

Three Gorge Reservoir configurations can contain floods up to the 1,000 year return period without discharging water in excess of the downstream channel capacity. Even in the event of an exceptional flood, the reservoir will allow additional warning over current conditions, giving authorities the time to more effectively organize massive evacuations.

Table XXXIV shows the estimated number of lives that will be saved by the alternative Three Gorge Reservoir configurations examined in this study. These numbers were calculated after examining, among other things, available information on major flood return periods and hydrographs, estimated warning times, and the shapes and sizes of the populated floodwater diversion areas. In view of the lack of information regarding these items, the number of lives saved by the project was set proportional to the number of temporary relocations saved during major flood events.

The Net Social Impact Curve. The final task remaining is the derivation of the social impact vs. dam height relationship. In order to derive this curve, the tricky question of present-worthing quality of life and the relative value of future lives had to be addressed. It is common knowledge that we do not value lives in the future as heavily as we do lives in the present. This is a natural characteristic of the personal perspective (Linstone).

During approximately forty interviews, the author found that some Chinese citizens place a discount rate of about 1.5 percent on future quality of life and the value of future lives. This was determined chiefly by asking persons how far into the future they would spend one

TABLE XXXIV

ESTIMATED LIVES SAVED BY THREE GORGE PROJECT FLOOD CONTROL OPERATIONS

Top of Dam Height (meters)	Bottom of Conservation Pool Elevations Relative to Top of Dam Height (meters);				
	-20	-25	-30	-35	-40
100	41	61	80	99	——
110	141	304	734	1,075	1,687
120	1,483	2,706	3,265	3,568	3,884
130	3,643	3,996	4,107	4,158	4,170
140	4,135	4,184	4,210	4,232	4,250
150	4,190	4,233	4,288	4,347	4,405
160	4,236	4,327	4,451	4,548	4,587
170	4,382	4,513	4,594	4,615	4,631
180	4,572	4,619	4,641	4,662	4,698
190	4,625	4,660	4,707	4,719	4,763
200	4,682	4,740	4,867	4,895	4,964
210	4,760	4,891	4,973	4,977	4,981

unit of money to prevent human suffering while setting such an expenditure equal in weight to half a unit of currency at the present time. The average answer was about 48 years. This discount rate, of course, is open to debate, since it was based upon a sample of only thirty persons, and might have been skewed for any one of a number of different reasons (sex, educational level, urban or rural background, age, religious affiliation, Communist Party membership, social standing, wealth, health, etc.). The primary usefulness of this discount rate for this study is merely to support the present-worthing of lives saved by the Three Gorge Dam. This matter should be investigated in more detail at some later date.

Table XXXV shows the magnitude of relative net social benefits accrued by various Three Gorge project configurations, based upon the ratings contained in Table XXXIII. Table XXXV and Figure 9 also show

TABLE XXXV

MAGNITUDE OF THREE GORGE PROJECT SOCIAL IMPACTS

Top of Dam Height (meters)	Bottom of Conservation Pool Elevation Relative to Top of Dam Height (meters);				
	-20	-25	-30	-35	-40

Unadjusted Rating (thousands)

100	10	25	44	61	—
110	60	190	530	802	772
120	1,111	2,071	2,512	2,753	3,003
130	2,796	3,076	3,165	3,206	3,218
140	3,157	3,198	3,224	3,244	3,260
150	3,033	3,126	3,205	3,251	3,297
160	2,756	2,877	2,992	3,068	3,102
170	2,572	2,677	2,743	2,762	2,783
180	2,464	2,502	2,521	2,538	2,568
190	2,354	2,396	2,448	2,460	2,510
200	1,255	1,309	1,413	1,442	1,506
210	266	370	437	445	475

Adjusted Rating (Scale: 0.0 to 10.0)

100	0.03	0.08	0.13	0.19	—
110	0.18	0.58	1.61	2.43	2.34
120	3.37	6.28	7.62	8.35	9.11
130	8.48	9.33	9.60	9.72	9.73
140	9.58	9.70	9.78	9.84	9.89
150	9.20	9.48	9.72	9.86	10.00
160	8.36	8.73	9.08	9.31	9.41
170	7.80	8.12	8.32	8.38	8.44
180	7.47	7.59	7.65	7.70	7.79
190	7.14	7.27	7.43	7.46	7.61
200	3.81	3.97	4.29	4.38	4.57
210	0.81	1.12	1.33	1.35	1.44

The present worth of one per period at 1.5 percent 114 years into the future is 54.455, and 15 years into the future (when the project begins flood control operations) is 13.343. Therefore, the factor by which the values of future lives saved by the project (+15) and future temporary relocations prevented by the project (+1) are multiplied is 41.112.

For example, for the project top-of-dam height of 190 meters and bottom of conservation pool elevation of 160 meters, the total present-worthed value of its net social benefits is;

((Temp. Reloc.) + (Lives Saved))(P/W) + (Perm. Reloc) = Total
((18,069)(+1) + (4,707)(+25))(41.112) + (599,000)(-2) = **4,383,000**.
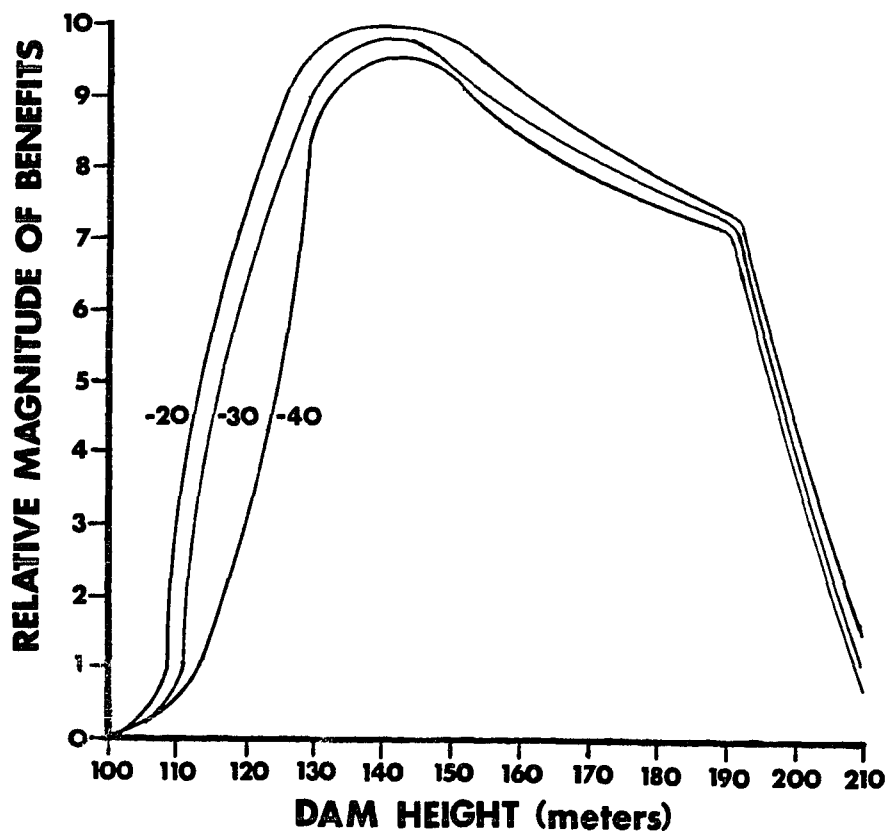
Figure 9. Magnitude of Three Gorge project net social impacts.
The numbers on the graph refer to bottom of conservation pool elevations relative to top of dam elevations.

the resultant weighted values of the social impact curves, based upon a

maximum weight of 10.0. This is equivalent to the 10.0 weighting given

to the maximum value of the economic impact curve.

CHAPTER VI

ENVIRONMENTAL CONSEQUENCES OF THE THREE GORGE DAM AND RESERVOIR

GENERAL PRINCIPLES

In today's world, developers and environmental groups must work together during all phases of the planning, design and construction of a large water resources project. It is not sufficient to hold a series of three or four general public meetings. Those who will be affected by a water resource development must be an integral part of the "team." This consultation process will be annoying at times to professional engineers and planners who may not be accustomed to working with those whom they consider to be "laymen." But they will find that every hour spent in researching the concerns of environmental groups and concerned citizens will pay handsomely in saved time and resources, and will reduce resentment among those not directly involved in a project's life cycle.

A good environmental study has numerous tangible benefits. Any government that is insulated from society, especially when it is planning a large water resources project, risks being perceived as unresponsive to the legitimate concerns of the people. Many apparently robust governments have blundered badly by attempting to plan and build a project while 'actively ignoring' the opinions of the people.

Lack of concern towards environmental matters may stall a project indefinitely. External financial aid may be withheld by international financing organizations such as the World Bank, which are becoming increasingly aware of project ecological impacts. The world 'environmental community' is organizing to block construction of large water projects all over the world, including several in China and the USSR (Moyes, 1986). This means that the Chinese must be especially rigorous in their documentation of Three Gorge environmental impacts and must firmly establish effective mitigative measures early in the planning process. If there are any serious shortcomings in Chinese environmental analyses, international environmental groups will ferret them out and use them in attempts to persuade the international banking community to adopt a "hands off" attitude towards Three Gorge Dam.

THE CHINESE PERCEPTION OF THE ENVIRONMENT

Many nations strive to preserve the environment for its own sake. In contrast to this attitude, the Chinese tend to refer to the environment from man's point of view. Nature exists to serve man. Any change made in the natural surroundings which betters his life is considered an 'improvement.' This viewpoint is reflected in engineering reports which include analyses of the benefits and costs of flood control works in the "environmental" section.

Chinese tradition refers to the environment as 'Fong-Shoei.' According to these beliefs, the earth is a living organism that may be angered or injured by man's careless acts (Chen, Jerry). The wisdom in this concept has been demonstrated many times by large water resource

projects which have created serious disturbances and imbalances in the local ecosystem.

SPECIFIC THREE GORGE DAM AND RESERVOIR ENVIRONMENTAL CONSEQUENCES

Many Western environmentalists are concerned that the anticipated impacts of the Three Gorge Reservoir will be glossed over during feasibility and advanced studies due to the project's enormous flood control and hydropower benefits. Detailed environmental impact studies have not yet been carried out in detail by the Chinese government, but an excellent framework is laid out in Volume VIII of the 1983 Feasibility Report. In view of the size of the project and the international attention focused on it, the Chinese are likely to carefully assess its consequences. The Bureau for the Protection of the Yangtze against Pollution, which was established in 1976, is devoted solely to the study of the environmental impacts of the Three Gorge Dam and Reservoir.

The construction of the Three Gorge project will certainly have immense impacts on the surrounding ecosystem. However, not all of the project's effects will be detrimental. The following paragraphs describe the impacts that most large man-made reservoirs could be expected to have on the living and non-living environment, and summarize the specific anticipated effects of the Three Gorge Dam and Reservoir.

RESERVOIR IMPACTS ON FISH

Resident Fish.

Cold-water resident (non-migratory) fish typically inhabit rapidly flowing streams at relatively high elevations, while most warm-water

fish prefer deep, sluggish streams or reservoirs and lakes. In general, therefore, the construction of many man-made lakes will tend to reduce cold-water fish habitat and create more for warm-water fish.

Cold-Water Fish. Cold-water fish prefer turbulent streamflows. A reservoir may aid these fish in downstream areas by augmenting natural seasonal low flows. However, there is a tradeoff with these releases, because the cooler water must be drawn from the lower levels of the lake. This water usually has the lowest oxygen levels and might have to be reaerated.

Warm-Water Fish. Warm-water fish consume food plants that grow at a depth of 3 to 15 meters depending upon the clarity of reservoir water. These plants have a low tolerance to changes in lake depth, so the warm-water fish population will decline if a lake's water level fluctuates drastically due to flood control or hydropower requirements. Conversely, a lake level which is kept relatively stable for the benefit of food plants will severely limit hydropower storage, with a resulting loss of energy generation.

Additionally, most warm-water fish cannot tolerate large lake elevation changes during their spawning cycles. A maximum fish population will naturally occur in a stable, shallow reservoir. This condition results in large lake evaporation losses, so once again there is a cost to hydropower generation.

Reservoirs supporting a warm water fish population must maintain a dissolved oxygen content above 85 percent of saturation, and pollutants may be present in only very low concentrations. Fortunately, fish

typically abandon waters that do not suit them long before fishkills occur.

Oxygen Supply Fluctuations. The requirements of resident fish must be met at all phases of project planning and construction, or a break in their life cycle may occur. The land that is to be inundated by a reservoir must be cleared of most of its vegetative matter, including grasses. Remaining organic material may rot quickly, releasing large quantities of nitrogen and phosphorous into the water. This may cause severe but temporary instability in a reservoir with a large volume of water exchange, because nutrients will lead to a quick increase in aquatic weeds and fish. If a reservoir has a low exchange ratio, such as the Brazilian Itapura and Curupachi lakes, all dissolved oxygen may be consumed by bacteria, leading to the killing of all fish. This break in the fish life cycle might take years of strenuous effort to overcome (MWREP, 1983b).

Reservoir stratification reduces the oxygen content of releases, and back-to-back reservoirs create long stretches of slackwater, retarding the reaeration that is supported naturally by turbulence. Due to the lack of natural reaeration in a reservoir, biodegradeable wastes break down much more slowly than in a free-flowing stream (Frey).

Migratory Fish.

Salmon and related species of migratory (anadramous) fish travel upriver to small streams to bear their young, generally in the late fall and winter. The fingerlings remain in this general area for one or two years, travel to the sea in the late spring where they stay for

one or more years, then return to their birthplace to spawn. A dam will naturally block this migration completely unless alternate spawning areas are provided or unless some way is worked out to allow fish to bypass the embankment. Bypass facilities must be designed to cause the least delay and physical exertion by the fish.

Bypass Methods. The most common bypass is a fishway, which allows fish to swim through a series of baffles with stillwater bays at each step to allow rest. The water velocity is held to less than 1.1 meters per second, and the facility is designed to accomodate the full anticipated range of tailwater and headwater fluctuations. These fishways are sized to pass the largest possible percentage of fish at the least possible cost. Since most species of tropical migratory fish avoid fish ladders, some other method of transportation may have to be used (Frey; Bell).

If a dam is very high, or if fish counts are relatively low, the fish may be transported past the dam by mechanical means (locks, elevators, or trucking). The fish are enticed by an attraction current, trapped in a hopper, then transported around the dam and placed in slackwater so that they have sufficient time to recover before resuming their migration.

If fish cannot be bypassed, or if all spawning areas are flooded (as on the Columbia River), fish may be trapped and their eggs removed and raised to fingerling size in a hatchery. The fingerlings can be released into the stream or transported downstream past all obstructions.

At some projects, including the Harry S. Truman Dam in Missouri, fish may be sucked into turbines or pumps and chopped to pieces. If this is a recurring problem, screens must be erected far enough upstream or downstream so that the fish are not crushed against them.

The legal headaches and wasted money caused by improper planning for fish needs can be of unbelievable proportions. For example, the Truman powerhouse may only operate at one-third capacity due to Missouri State restrictions, and its 160-megawatt pumpback capability, which cost an additional twenty million dollars to install, has never been used. This has disrupted power planning for the entire power supply area. The North Pacific Division of the U.S. Army Corps of Engineers is now undertaking detailed (and very expensive) studies to determine how many of the six state-of-the-art slant-shaft turbines may be operated without incurring excessive paddlefish mortality.

Three Gorge Dam Impacts on Fish.

The construction of a dam at Sandouping will dramatically change the character of the Yangtze River between Chongqong and the exit of Xiling Gorge. Currently, the river squeezes its vast flow through gaps as narrow as 110 meters, and water traverses the Chongqing-Yichang reach in about two days. After the construction of the Three Gorge Dam, this reach will more closely resemble a very deep and slow river. Despite the large storage volume of the Three Gorge Reservoir, the project will not have seasonal storage, because Yangtze River water will languish in lake form for an average of only two weeks.

The Chinese government has identified 274 species of freshwater fish native to the Yangtze river system, including anadramous fish such

as the endangered Chinese giant sturgeon (Acipenser Sinensis), China's "four farm fishes" (silver, bighead, black and grass carp), and a rare species of alligator (Liu; MWREP, 1987). Of these, 82 species live in the river reaches upstream of Gezhouba Dam (LaBounty). Some of these species are unique to the river, and the effects of a giant dam upon them has not been assessed in detail.

Food Fish Production. Currently, about half of the national total (750,000 tonnes) of freshwater fish are taken from rivers in the Yangtze basin. However, only about three percent of this fish is produced by the basin upstream of Yichang (MWREP, 1983b). Since Gezhouba Dam already blocks the main stem of the Yangtze, the additional loss in freshwater food fish caused by Three Gorge is assumed to be negligible.

The Three Gorge Reservoir will have at least 133,000 hectares of water surface area, and therefore has great potential for food fish breeding in view of experience gained at other large Chinese reservoirs (EW, 1985). For instance, fish production on the Han River has increased by a factor of 18 since the construction of the Danjiangkou multiple-purpose dam and reservoir (MWREP, 1983b).

The Sturgeon. The Chinese giant sturgeon grows to a maximum of four meters length and 600 kilograms weight. Chongqing's Changshou Lake Fish Culture Research Institute, in anticipation of the closure of Gezhouba Dam, managed to develop the technology necessary to successfully breed the Chinese giant sturgeon and the Yangtze sturgeon (Acipenser Dabryanus). The Aquatic Products Department of the Gezhouba Engineering Bureau then, at great expense, reintroduced about 120,000

of the Institute's fry into the Yangtze upstream of Gezhouba Dam (Jianqun). At approximately the same time, the Aqua-Bio Research Center of the Chinese Science Institute revealed that the Chinese Sturgeon, blocked from migration by Gezhouba Dam, was breeding competently in the stilling basins of the project. This made them easy prey for fishermen. Chinese authorities have now restricted fishing in the area immediately downstream of Gezhouba Dam, and the Yangtze Sturgeon population is increasing rapidly.

Three Gorge Reservoir Effects upon Water Temperature. Extensive fish mortality may be caused by rapid water temperature changes. However, these changes are expected to be insignificant at the Three Gorge Reservoir, because reservoir storage capacity is equivalent to only about four percent of the Yangtze's average annual flow. The total water temperature change induced by the reservoir body is expected to range from +0.2 to +0.5 degrees Centigrade in the winter season, and -0.4 to -1.5 degrees Centigrade during the summer (MWREP, 1983b).

RESERVOIR IMPACTS ON WATERFOWL

Long before the construction of any large water resource project, responsible agencies must conduct a comprehensive biotic inventory both in the area of the reservoir and in possible mitigation areas. Threatened or endangered species must be moved and provided mitigative habitat of equal or greater value than that which they previously occupied.

Governments have occasionally ignored the ecological impacts of construction and have suffered the consequences. In 1955, spectacular

Lake Pedder, Tasmania, was made into a national park. This lake was considered one of the three premier tourist attractions and biological preserves in Australia. Despite bitter opposition, this great resource was flooded under 15 meters of water in 1976.

Perhaps because of debacles like this, the World Bank, before it will consider financing all or part of a project, now requires that all habitat lost must be mitigated at project expense by setting aside permanently protected areas of equal or greater value (Goodland).

Ducks, geese and other migrating waterfowl require large, shallow lakes with sufficient food plants to support them and their small prey. A new lake will provide a resting and nesting area for migrating waterfowl and will inundate brushy areas along streams that serve as home to such species as deer, bear, and squirrels (McGinnis). However, the draining or submergence of flyway habitat will confuse and hamper migration. It may be possible to flood low marshy areas near natural flyways that will replace those that have been inundated by a reservoir, if land costs are not prohibitive. The original habitat balance may require several years to establish itself in a mitigation area.

RESERVOIR IMPACTS ON INSECT LIFE

General Principles.

The construction of a reservoir in tropical or subtropical areas may encourage the breeding of certain dangerous insect and related pests. These may have a profound impact on the local populace, to the point of shortening human life spans considerably. Table XXXII in Chapter V lists some of the dangerous disease vectors that may be

introduced to an area conditions brought about by the construction of a reservoir. Such infestations must be anticipated and dealt with before and during project construction. If the problem is ignored, or detected only after the project is built, much unnecessary suffering and expense will result. It is always easier to prevent the introduction or spreading of insect pests than it is to eradicate them.

Mosquito. Malaria and yellow fever may be transmitted by certain species of mosquito, which require shallow, stable pools in which to breed. The construction of a large reservoir in in an area of rugged topography will create hundreds of linear kilometers of narrow backwater marshes, which are ideal for mosquito breeding. For example, after the Danjiangkou Reservoir was filled, malaria incidence in the immediate area increased from 1.3 percent to 7.6 percent (MWREP, 1983b).

Most mosquito breeding areas can be cleared by changing reservoir water surface elevation at a rate of about 0.3 meters per week, which is too small a variation to harm fish. The Tennessee Valley Authority has developed unusual reservoir rule curves which allow weekly fluctuations of pool levels during the mosquito breeding season.

The magnitude of mosquito breeding has been found to be directly proportional to the water area covered by phreatophytes (James). If a reservoir is large, plant or insect control measures may require impractically large storage releases, and stagnant areas along the lake must then be sprayed.

Blackfly. The blackfly (aptly named Simulum Damnosum) breeds in rapids and inflicts river blindness (Onchoerciasis). The construction

of a reservoir or irrigation scheme will naturally eradicate the insects where rapids or fast-moving waters are submerged.

Bilharzia (Ting) Snail. In contrast to mosquito control operations, longer-cycle reservoir fluctuations are required to control bilharzia (schistosomiasis) snails. They may also be progressively displaced over a period of years by the larger Marisa Cornuarietis snail. These parasites live in freshwater pools in the Caribbean, Brazil, Africa, the Phillipines, the Middle East, and the People's Republic of China (Jobin).

Three Gorge Reservoir Impacts on Insect Life.

The bilharzia snail exists to a limited extent in the upper reaches of the Yangtze and two of its larger tributaries, the Min and Tuo Rivers. The snail was, at one time, widespread in the lower reaches of the Yangtze as well. However, intensive efforts by the Chinese government have eradicated the pest completely in large areas. In the mid-1950's, bilharzia was endemic in the area surrounding Yichang. Now an average of five cases are reported each year (MWREP, 1983b).

The construction of the Three Gorge Reservoir is expected to reduce the incidence of Snail Fever and malaria in existing downstream floodwater retention areas, but this benefit may be offset by allowing these diseases to gain a foothold in upstream slackwater areas. The snail is not expected to multiply in the reservoir itself due to unfavorable breeding conditions caused by large water surface fluctuations between steep canyon walls. The possibility of localized infestation does not particularly concern the Chinese government, which

has long experience in effectively controlling such waterborne diseases. Drainage channels will be constructed in swampy headwater reservoir regions, so that standing water may be removed as the reservoir level drops (Tingzheng, 1985).

RESERVOIR IMPACTS ON WATERBORNE PLANTS

Aquatic weeds (phreatophytes) can grow with incredible speed in tropical and subtropical areas (i.e., the Aswan Dam in Egypt and the Kariba Dam in Zambia and Rhodesia). An outstanding example is Lake Brokopondo in Surinam. Water hyacinth advanced to cover 410 square kilometers of this lake between February 1964 and April 1966 (this is an average advancement rate of six square meters of coverage per second over a period of more than two years). Attempts to rid lakes of these pests with chemicals often aggravates other sectors of the ecosystem. Additionally, evapotranspiration losses due to phreatophytes can be enormous (Biswas, 1980).

RESERVOIR IMPACTS ON THE NON-LIVING ENVIRONMENT

Introduction.

Aside from its considerable effects upon fish, waterfowl, and insect life, a reservoir and its operating regime will have substantial indirect impacts upon a large surrounding area. The effects of the Three Gorge Reservoir on the non-living environment will be both beneficial and potentially harmful, as outlined in the following paragraphs.

Microclimate Effects.

The average annual temperature in the Gorges is about 17.5 degrees Centigrade. The area is frost-free year round, and the growing season

of ten months is fully one month longer than adjacent regions immediately outside of the Gorges. These mild temperatures and an annual average precipitation of 1,100 millimeters make the steep slopes of the Yangtze Gorges ideal for growing oranges.

At a water elevation of 160 meters, the Three Gorge Reservoir will extend from 107 degrees to 111 degrees East latitude and 30.5 degrees to 31.5 degrees North longitude. The water surface area will change from 277 square kilometers to about 719 square kilometers (USDMA; MWREP, 1983b). Upon reservoir filling, the fast-flowing Yangtze will be abruptly replaced with a smoother water surface approximately one kilometer in width. Wind currents will encounter less friction on the water surface, so it is expected that velocity will increase an average of 25 percent to 45 percent (MWREP, 1983b). This may, in turn, help dissipate fog in certain habitually cloudy upstream areas of the Gorges. There will also be less mixing of air, but only minor precipitation changes are expected.

Estuary Effects.

Reservoirs may augment low river flows in order to retard the flow of salt water into an estuary. Locally, salt intrusion was measured as far upstream as the town of Bonneville before the first reservoir was constructed on the Columbia. In a river system without reservoirs, salt water will travel upstream approximately to the point where the river bottom rises above sea level during periods of low flow, possibly contaminating nearby groundwater. Low-flow augmentation also serves the purpose of reducing potentially harmful concentrations of certain pollutants in an estuary.

Low flow augmentation releases from the Three Gorge Reservoir will lead to average estuary salinity reduction at Shanghai from 0.110 percent to 0.077 percent. More importantly, the relatively even flows from the Three Gorge-Gezhouba reservoir system will interfere with the complex saline circulation system of the delta. This circulation enhances the continuous exchange of nutrients between the ocean and the river, and any disruptions could have profound consequences, similar to those on the Nile Delta, where 95 percent of the eastern Mediterranean's sardine catch has been lost (USBR, 1984; Lavergne).

Landslides and Induced Seismicity.

Water is exceedingly dense; a cubic meter of the substance weighs a metric ton. A reservoir which impounds a cubic kilometer of water will cause an almost instant addition (in geologic terms) of a billion metric tons on supporting strata. This will lead to consequences ranging from numerous small stress-relieving earthquakes to catastrophic quakes and slides similar to the events that destroyed India's Koyna Dam and killed thousands in 1967 (Goodland). Table XXXVI lists major confirmed and suspected seismic events caused by reservoir filling.

The Sanxia Seismic Station, erected in 1959, has recorded 580 tremors within seventy kilometers of the Sandouping damsite. Ten of these have had a magnitude of 3.0 or greater on the Richter scale (MWREP, 1983b). The National Seismic Bureau and the Seismic Bureau of Hubei Province have determined that the probable maximum earthquake that could occur under the dam or reservoir would be of magnitude 6.0. The maximum proximate earthquake, of magnitude 6.5, would occur on the

Yuanzhunxiang seismic belt at a distance of about sixty kilometers from the dam (Moyes, 1986). None of these events is expected to pose any serious danger to the Three Gorge embankment.

Over the last half-century, sixteen major landslides into the Yangtze River reach from Wanxian to the Sandouping damsite have been catalogued. These slides ranged in volume from 3.3 million to 15 million cubic meters. Studies have suggested that, after reservoir filling, there is little probability that a slide of greater than 2.5 million cubic meters volume will occur within twenty kilometers upstream of the dam (MWREP, 1983b). Such slides are not expected to endanger the dam or cause overtopping.

Historical Resources.

The Three Gorges area has been inhabited for thousands of years, and archeological exploration and recovery missions will be expensive. A comprehensive inventory and salvage of significant cultural resources is now required by the World Bank before it considers financing all or part of a project.

RESERVOIR IMPACTS ON WATER QUALITY

General Principles.

A reservoir may radically change the nature the water that passes through it. The water discharged from a man-made lake will differ from the water that flowed into it in terms of quantity and dissolved oxygen, nutrient, sediment, and pollutant concentrations.

Water may be withdrawn from a reservoir and be put to many different consumptive and nonconsumptive uses. Alternatively, it may remain in the lake to be used for navigation, hydropower generation,

TABLE XXXVI

CONFIRMED AND SUSPECTED SIGNIFICANT SEISMIC
EVENTS CAUSED BY RESERVOIR FILLING

Name of Project	Country	Year of Event	Magnitude of Event
Koyna	India	1967	6.5 *
Kremasta	Greece	1966	6.3
Kremasta	Greece	1965	6.2
Hoover	United States	1939	6.1
Hsinfengkiang	PRC	1962	6.1 **
Kariba	Rhodesia	1963	6.1
Oroville	United States	1975	5.9
High Aswan	Egypt	1981	5.6
Bajina-Basta	Yugoslavia	1967	5.0
Benmore	New Zealand	1966	5.0
Marathon	Greece	1938	5.0
Monteynard	France	1963	5.0
Kurobe	Japan	1961	4.9
Nurek	USSR	1972	4.5
Vouglans	France	1971	4.5
Clark Hill	United States	1974	4.3
Alensani	Corsica	1978	4.0
Viaont	Italy	1963	***

Reference; Goldsmith
* Seismic event damaged embankment. 177 persons killed.
** Seismic event damaged embankment.
*** Seismic event led to large earthslide into reservoir, which caused a wave to overtop the dam, killing more than 2,000 downstream.

recreational purposes, and waste dilution. Not all of these purposes are compatible; if water is contaminated with certain pollutants, it is rendered less desirable for other uses.

It is not feasible to allow unlimited discharge of wastes into a stream, which used to be common practice in certain European nations. The other extreme - zero pollutant discharge - is also impractical. The water resources planner must strike a balance between these two

points so that the water is used for purposes that yield the greatest net benefits.

Pollutant Varieties.

There are literally hundreds of compounds that are dumped into the world's rivers every day. Some of the most common pollutant groups are listed below (James);

* Degradable wastes

    domestic sewage
    heat
    plant nutrients (phosphates)
    bacteria and viruses
    noncolloidal sediments

* Nondegradable wastes

    salts
    radioactive wastes
    inorganic chemicals
    agricultural wastes
    colloidal suspensions

Dissolved Oxygen. Degradable wastes are consumed by micro-organisms which use a quantity of oxygen proportionate to their population, which is in turn dependent upon pollutant concentrations. If their biological oxygen demand (BOD) leads to a precipitous decline in a stream's dissolved oxygen, fish kills and decomposition retardation will result, leading to foul odors.

Excessive heat discharge into a stream will also reduce dissolved oxygen. The oxidation of organic matter in streams and in treatment plants liberates phosphates and other nutrients, which lead to the uncontrolled growth of some aquatic plants (phreatophytes). These plants are capable of clogging waterways and intakes, and may lead to unpleasant odors through eutrophication.

Sediment and Nutrient Precipitation. Water will naturally slow as it enters a reservoir. Since the particle carrying capacity of a stream is proportional its velocity, the water will drop part of its

sediment load, reducing turbidity but increasing channel scour in downstream reaches. This process is beneficial from a navigation standpoint, because it reduces the costs of downstream dredging. However, the silt and nutrients that precipitate in the reservoir are no longer available to nourish lands and estuaries downstream, and cutback can occur, as on the Nile River.

Pollutant Concentrations.

Evaporation may consume up to half of the inflow of a reservoir constructed in an area with an extremely arid climate. One example of this phenomenon is Egypt's Lake Nassar. Since less water leaves the reservoir, pollutant concentration will be greater in downstream reaches.

The annual precipitation onto the relatively small surface of the Three Gorge Reservoir will exceed the estimated annual evaporation, so losses due to natural processes will not be a problem for the project.

The Consequences of Good and Bad Water Quality.

In general, the water quality costs of a project equal the expenses of treating the water that it has degraded so that it is equivalent in quality to its original state. The water quality benefits of a project equal the avoided cost of damage caused by poor-quality water that would be incurred in the absence of the project. The benefits and costs of good and bad water quality are summarized below.

The Benefits of Good Water Quality. When a water resource project actually improves the quality of the water that passes through it, benefits may be claimed, including (Howe, Charles);

* the value of improved health to those who currently drink and
   use untreated water,
* reduced intake water treatment costs at downstream cities
   (municipal and industrial use),
* increases in desirable sports that involve contact with water
   (swimming, boating, fishing, water skiing),
* improved waterway aesthetics,
* the value of useful byproducts recovered from streams, and
* reduced flood damages due to better-quality water.

The Costs of Bad Water Quality. As water quality is degraded, it

becomes less useful to users downstream. Each user of poor-quality

water has one of several options;

* use the poor-quality water and suffer economic losses,
   including equipment damage,
* change water use to those times when water quality is higher
   (during high flows or noncoincedent use by others),
* develop an alternate supply of water, such as groundwater, or
* raise the quality of the water to acceptable standards by
   treating it.

The damage each user suffers is the cost of the least-expensive

combination of the above mitigation measures available to him. The

damage for all users is summed and added to the damage suffered by

those who have no alternative but to use the poor-quality water without

treatment.

The construction of those facilities that are specific to the

improvement of water quality must be counted as costs to the project as

a whole. These costs may include;

* the construction cost of treatment facilities,
* operation and maintenance of the facilities,
* increased air pollution resulting from the burning of trash and
   sludge from the treatment plants,
* the treatment of plant odors,
* the costs of disposing of solid wastes from the treatment
   plants, and
* the possible loss of jobs in those plants forced to install
   water pollution abatement equipment.

Measuring the Damages Caused by Individual Pollutants.

Generally, the majority of water pollutant damage in a particular stream is caused by only a few agents, and a relationship between concentration, frequency, and damage may be derived for each one. Because the effects of combinations may be synergistic, it is obvious that such a study will be enormously expensive and detailed, and so assumptions and estimates must be made. Individual pollutants generally cause no significant damage until they reach a certain threshhold concentration, then damage increases rapidly to a point where it levels off, because water quality is so bad it can cause no further damage (or its use is simply discontinued by everyone).

Damage estimating is difficult, but not impossible. Major water users may be interviewed to determine what measures they will take to combat the rise in concentration of important pollutants, and what the costs for these measures are. Sometimes, organizations will have actual cost figures on hand after damaging incidents of concentrated pollution.

Assessing crop loss caused by increased water salinity involves relatively straightforward calculations. Salt leaching is vital to crop growth. The costs of leaching may be equated to the cost of obtaining good-quality water to use as a leachant. If no water of good enough quality is available, costs may be set equal to the income foregone by farmers when they switch to growing a less-desirable but more salt-resistant crop (James).

The Problem of Conflicting Water Uses.

The many uses of water are not always compatible from a water

quality standpoint. Irrigation waters may be returned to a stream with higher salt and fertilizer contents. Treatment plants may discharge waters with a high concentration of compounds which may cause soil pore clogging or encrusting if such water is used for irrigation. Clearcutting increases sediment load, and this sediment fills up reservoirs and decreases flood control capacity. Fish hatcheries are severely affected by wastes which are discharged upstream. Water plunging from hydro plants will dissolve nitrogen and may injure or kill fish. Most pollutants will decrease the desirability of recreation in a reservoir. To summarize, as a general rule, water put to any use will almost always adversely affect one or more other uses.

Three Gorge Reservoir Impacts on Water Quality.

Industrial Pollutants. The major industrial city of Chongqing is located at the headwater of the proposed Three Gorge Reservoir. Industries in the city discharge pollutants into the river, including heavy metals and compounds such as cyanide, mercury, copper, arsenic, chromium, zinc, oils and lead. These materials remain in suspension under current conditions, but if a reservoir is constructed, they may precipitate in bottom muds, perhaps accumulating in dangerous concentrations.

Construction of the project, with its accompanying flood control benefits, will also probably lead to extensive industrial and residential development along the shores of the Yangtze River below Yichang. The effects of an increased pollutant load on local and area groundwater has not been studied.

Water-Soluble Soil Components. If a large surface area of water-soluble carbonaceous minerals are exposed to water after inundation, the reservoir will experience an increase in calcium and magnesium ions, resulting in harder water. The surface soils that will lie under the future Three Gorge Reservoir contain little carbon-bearing rock, so the increase in water ion concentration is expected to be minor (MWREP, 1983b).

Floating Debris. The Three Gorge Reservoir will drain an area of more than a million square kilometers. Many large streams, originating and flowing through woodland and farmland, will discharge directly into the lake. Following floods, a large quantity of floating debris, including wood and large dead animals, is expected to accumulate near the upstream side of the dam. Since this mass will consist primarily of organic matter, it must be removed in order to avoid localized pollution, oxygen degradation, offensive odors, and possibly disease incidence. Large quantities of rotting matter in the immediate vicinity of the dam will adversely affect the tourist industry as well.

RESERVOIR IMPACTS ON AIR QUALITY

Introduction.

The assessment of the environmental benefits and costs of a large hydropower plant should continue uninterrupted throughout the reconnaissance, feasibility, and design studies. Generally, hydropower benefits result from the displacement of coal-fired generation, and its costs accrue as a result of the construction of a reservoir. The air quality benefits that may be ascribed to hydropower operation are described in the following paragraphs.

Fossil Fuel Displacement.

Introduction. Hydropower generation may be used to displace more expensive coal, oil, and gas-fired generation. Hydro is essentially pollution-free, and therefore provides substantial benefits to the environment in terms of cleaner air. The environmental benefits of hydropower could be set equal to the avoided damage of alternative fossil-fuel plants providing the same amount of energy.

The clean power provided by the Three Gorge project, if used exclusively to displace coal-fired generation, would reduce the amount of coal burned in the project service area by 32 million tonnes per year. This would result in an annual reduction of 1.4 million tonnes of sulfur gas, 8.5 million tonnes of airborne ash, and 180,000 tonnes of nitrogen trioxides discharged into the atmosphere (EPRI; USBR, 1984).

The advantages of hydropower generation over fossil fuel energy are summarized in the following paragraphs.

Advantages for Human Health. The process of mining coal can be extremely hazardous and is subject to productivity losses and increased health care costs caused by serious accidents and respiratory ailments. These problems are particularly acute in China's small, unmechanized local coal mines.

Past studies have attempted to quantify fatality rates in terms of deaths per unit of coal-fired and nuclear generation per year. Occupational and on-site hazards can be quantified rather easily. However, the extreme conditions of uncertainty associated with estimating fatalities due to air pollution and gaseous radioactive

materials releases make estimates of life-threatening impacts virtually impossible. Therefore, there is really no way of knowing how many lives hydro generation may actually save as it displaces coal-fired generation, or, indeed, if it saves any lives at all (Corps, 1981).

Of course, it would seem obvious that hydropower generation contributes substantially to cleaner air and, therefore, to better health. However, once again, it is impossible to make supportible estimates of this benefit.

Advantages for Animal Health. Hydropower does not cause the damage to streamdwelling animals, plants, and fish which are typical results of acid rain and the leaching of tailings from coal mining. Additionally, thermal pollution is not a problem with hydro as it is with coal-fired generation. The sole exception may be severe thermal stratification in a large reservoir, combined with releases of very warm water which will cause undesirable downstream impacts.

Advantages for Vegetation Health. Hydropower does not produce the acid rain that is now so much of an issue in many parts of the world. It also does not contribute to global warming brought on by the combustion of fossil fuels. Atmospheric carbon dioxide is increasing now at a rate of about one percent per year, and has escalated a total of 25 percent since the Industrial Revolution (Corps, 1981). This may lead to two major impacts: the disruption of agriculture, especially in Africa and Asia, due to climate shifts, and the flooding of large areas of lowland due to polar ice melting. Once again, there are no certain yardsticks with which to measure these effects. Global CO_2

escalation may be harmless, or it may be an irreversible knell of doom to many poorer countries.

Advantages for Materiel "Health." Many of the oxides emitted by coal-fired plants will degrade metal and rubber over time. This problem is avoided or decreased with hydropower. Hydro also has advantages in terms of the avoided costs of cleaning homes, vehicles, and clothing (Qayum, 1983).

Progressive damage to cultural and historical artifacts and structures is decreased in areas with a high percentage of hydro installed capacity. The problem of artifact deterioration is especially pressing in Europe, and is of particular concern in the Mediterranean area.

DERIVATION OF THE DIMENSIONLESS NET ENVIRONMENTAL IMPACT CURVE

Introduction.

Based upon the possible impacts that the Three Gorge Dam and Reservoir may have upon the surrounding environment, relative impacts are specified in Table XXXVII and are plotted in Figure 10. All of these effects occur regardless of interest rate, so no present-worthing or annualizing of any of the impacts is necessary.

Relative Magnitudes Assigned.

The relative impact magnitude assigned to the permanent inundation of land is based upon an arbitrarily assigned value of -1 for each 25 square kilometers flooded. The relative magnitude of the aggregation of all Three Gorge project environmental impacts is assigned a value of 10.0, identical to the maximum value of the project's economic impacts and social impacts. In order for the impact magnitudes to have their

TABLE XXXVII

RELATIVE MAGNITUDE OF POSITIVE AND NEGATIVE
THREE GORGE PROJECT ENVIRONMENTAL IMPACTS

Relative Weight	Description of Impact
+15	Air quality advantages over alternative thermal generation
+5	Enhanced food fish production
+5	Curtailment of bilharzia and malaria in downstream areas
+2	New upstream habitat for fish and waterfowl
+1	Microclimate effects (fog dissipation)
Unknown or Unlikely |/	Changes in reservoir temperature
	Temperature stratification
	Invasion of reservoir by disease vectors
	Invasion of reservoir by phreatophytes
	Blockage of fish migration routes
	Seismic effects
	Reservoir fluctuation (rule curve and flood control operations)
-1	Permanent inundation of 25 square kilometers of land
-5	Disruption of estuary saline exchange pattern
-5	Submersion of unsalvageable cultural and archeological resources
-5	Sediment catchment (downstream nutrition degraded)
-5	Increases in water pollution due to upstream industrial and residential development brought on by reservoir construction

- -

MAGNITUDE OF TOTAL RELATIVE ENVIRONMENTAL IMPACTS

Top of Conservation Pool Elevation	Land Inundated	Relative Magnitude Unscaled	Scaled
90 meters	95 square kilometers	9	+1.55
100 meters	148 square kilometers	7	+1.21
110 meters	203 square kilometers	5	+0.86
120 meters	288 square kilometers	1	+0.17
130 meters	374 square kilometers	-2	-0.35
140 meters	465 square kilometers	-5	-0.86
150 meters	571 square kilometers	-10	-1.72
160 meters	719 square kilometers	-16	-2.76
170 meters	907 square kilometers	-23	-3.97
180 meters	1,135 square kilometers	-32	-5.52
190 meters	1,415 square kilometers	-44	-7.59
200 meters	1,783 square kilometers	-58	-10.00
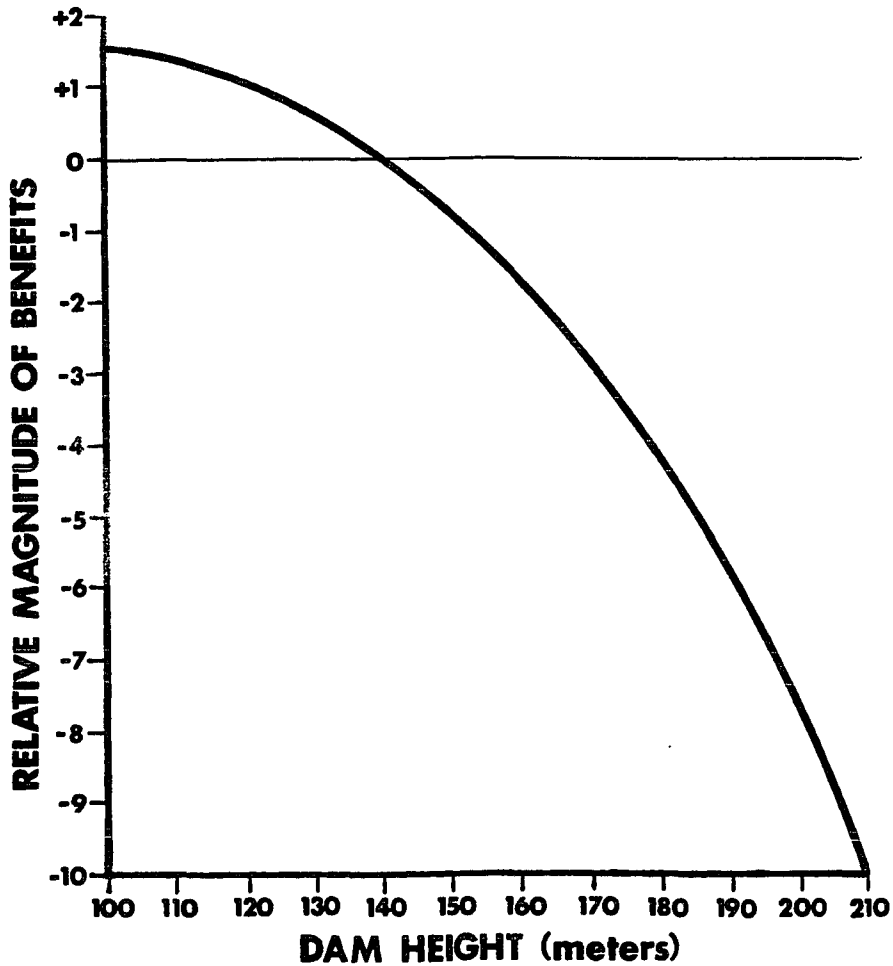
Figure 10. Relative magnitude of Three Gorge project environmental impacts. The top of conservation pool elevation is ten meters below the top of dam height.

greatest validity, they should be assigned by Chinese government officials, environmental experts, and the persons directly affected by the construction and operation of the Three Gorge project.

CHAPTER VII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

INTRODUCTION

Overview.

There are literally millions of possible Three Gorge project configurations that are feasible from an engineering standpoint. The evaluation of these alternatives is vastly complicated by a variety of fluctuating economic and demographic indicators, to include population distribution and growth, interest rates, fuel cost escalation rates, and inflation rates.

The general objective of a reconnaissance study is to define a smaller range of economically feasible project alternatives. More detailed feasibility reports further narrow the range of projects that maximize total net benefits and are financially viable. This smaller set of project configurations may vary significantly with the prevailing interest rate and with a cluster of other assumptions.

The purpose of this dissertation is to review the method by which the almost infinite universe of project alternatives may be reduced to a manageable number early in the study. This will allow the study team to save time and money by focusing their efforts on a narrower range of alternatives at an earlier point in the study.

Chapter Summary.

This chapter is divided into four sections;

(1) a review of the results of the studies on the Three Gorge project's economic, social, and environmental feasibility;

(2) a description and example of how these indicators may be combined toyield a single impact curve;

(3) an examination of the degree of sensitivity of the final impact curve to selected weighting and interest rate changes; and

(4) recommendations for further study by the Chinese government.

REVIEW OF THE STUDY

Review of the Overall Procedure.

This section reviews the findings of Chapters IV, V, and VI regarding the economic, social, and environmental viability of the Three Gorge Dam and Reservoir.

In brief, a favored reservoir configuration for each of a range of dam heights is determined during the economic study, and then the optimum dam height among this set is selected after combining the economic, social, and environmental (ES&E) net benefit curves. This process, as it has occurred in this study, is reviewed below;

(1) begin by selecting for study a range of dam heights which are condidered physically possible. The range of dam heights selected initially in this study is the range which has been examined by the Chinese government over the last twenty years (100 to 210 meters). Also select a corresponding range of pool elevations for each top of dam height. This study examined a top of conservation pool elevation ten meters below the top of dam height and a bottom of conservation pool twenty to forty meters below the top of dam height, in five meter increments. Although other top of conservation pool elevations are possible, this selection was considered optimum in light of the rarity of summer Yangtze River floods.

(2) narrow the range of possible bottom of conservation pool elevations during the flood control study. As described in Chapter IV, the bottom of conservation pool elevation was set twenty meters below the top of dam height because the incremental flood control benefits to be gained by lowering the bottom of conservation pool elevation would be more than offset by the resulting loss of incremental hydropower benefits.

(3) select an optimum installed hydropower capacity for each interest rate. Although four interest rates were examined during this study, only the seven percent interest rate is contained in the body of the study. Calculations regarding the other three interest rates are contained in (Clowes, 1987c).

(4) calculate navigation and recreation net benefits and check to see if these are significant enough to alter the above reservoir configurations. The top of conservation pool elevation is still assumed to be ten meters lower than each top of dam height, and the bottom of conservation pool elevation is assumed to be twenty feet lower than each dam height.

(5) derive the social and environmental impact curves. These curves are based upon the social and environmental impacts accruing to the project's water elevation at the top of conservation pool, and so will be largely independent of the bottom of conservation pool elevation and the top of dam height.

(6) finally, combine the ES&E curve indicators to determine the range of optimum dam heights for the range of expected interest rates.

Review of Project Economic Feasibility.

Flood Control. This study examined sixty alternative Three Gorge reservoir configurations. The top of dam height ranged from 100 to 210 meters in ten meter increments, and the bottom of conservation pool ranged from 20 to 40 meters below each dam height in five-meter increments.

Net flood control benefits were defined as temporary relocations and damages avoided by project flood control operations, less the

temporary and permanent relocations and damages caused by project construction and flood control operations.

Table XVIII and Figure 5 of Chapter IV show the results of this study. The range of dam heights showing a net flood control benefit is 110 meters to 190 meters for an interest rate of three percent. This range narrows to 110 to 150 meters at an interest rate of nine percent.

For a specific dam height, maximum net flood control benefits accrue to that project configuration which possesses the most floodwater storage volume, or the lowest bottom of conservation pool. Theoretically, maximum flood control benefits would accrue to a "dry dam," which is considered infeasible due to foregone hydropower benefits.

If a specific dam height is selected, the increase in net benefits as floodwater storage volume increases is relatively insignificant. An incremental increase in floodwater storage is used less and less frequently as a flood's return period increases. This means that the annualized value of avoided damages becomes smaller and smaller. Since incremental hydropower benefits for higher bottom of conservation pool elevations will more than offset the loss in incremental net flood control benefits, the study proceeded with a top of conservation pool elevation ten meters below the top of dam height, and a bottom of conservation pool elevation twenty meters below the top of dam height.

The lower dam elevations (100 to 110 meters) and higher dam elevations (170 meters and higher) cause a loss in net benefits at all interest rates from three percent to nine percent because the flood damages they prevent cannot make up for the initial huge cost of

permanent relocation and farmland inundated in order to make way for reservoir filling.

This study showed that the optimum dam height for flood control operations was 140 meters for each of the four interest rates examined.

Hydropower. This study examined 22 different installed hydropower generating capacities ranging from 1,000 megawatts to 31,000 megawatts for each of the twelve dam heights previously mentioned (100 meters to 210 meters, in ten-meter increments).

Net hydropower benefits are defined as the annualized cost of constructing and operating the without-Three Gorge power system minus the annualized cost of constructing and operating the with-project power system.

Table XXIV and Figure 7 of Chapter IV show the results of this study for a seven percent interest rate. The optimum installed hydropower capacity for this project ranges from 25,000 megawatts for the lower dam heights to the maximum possible installed capacity of 31,000 megawatts for dam heights of 140 meters or higher.

The optimum capacity fluctuates somewhat as the interest rate changes; from 25,000 megawatts at an interest rate of three percent to 27,000 megawatts at interest rates of five and seven percent, to the maximum of 29,000 megawatts for an interest rate of nine percent.

Navigation. Navigation benefits are independent of the top of dam height in this study. Their magnitude is determined instead upon the average pool elevation of the reservoir throughout the year.

Navigation benefits do not vary substantially with pool elevation, or with variations in the bottom of conservation pool elevation for a

specific dam height. Even the lowest pools studied (70 to 80 meters) will cover most or all of the dangerous Three Gorge passage, whose swift water currents cause an inordinate amount of fuel consumption on the upstream journey from Yichang to Chongqing. Between the upstream entrance to the Three Gorges and Chongqing, river velocity is relatively slow, and the time and fuel expended to traverse a slackwater lake between these two points would not be significantly less than that expended under current conditions.

The results of this study are shown in Table XXVI of Chapter IV.

Recreation.

The Chinese, and many foreigners, have been fascinated with the Three Gorge project for more than half a century. It has assumed almost legendary proportions in the minds of many, despite the fact that the first cubic meter of concrete has yet to be placed.

In all probability, the dam and reservoir will augment the Three Gorges themselves as a major tourist attraction, regardless of the dam height that is eventually selected. For this reason, the present-worthed recreation benefits that will accrue to the project will be largely independent of dam height or reservoir configuration.

<div align="center">CONCLUSIONS</div>

Introduction.

The stated primary purpose of the Three Gorge Dam and Reservoir is flood control. Therefore, if operation for flood control overrides all other project purposes, the dam and reservoir should be built to maximize annualized net flood control benefits, and every other purpose should be optimized with respect to flood control.

This study disregards this constraint. It instead attempts to optimize the Three Gorge Dam and Reservoir from a combination of the economic, social, and environmental (ES&E) viewpoints. The following paragraphs describe the procedure which combines the three impact curves derived in Chapters IV, V, and VI, and outlines the conclusions that can be drawn from the results of this process regarding the optimum Three Gorge project configuration.

The Procedure: Combining the ES&E Indicators.

Overview. This section describes the results of combining the weighted economic impact values in Table XXX (Chapter IV, pages 237 and 238), the weighted social impact values in Table XXXV (Chapter V, page 266), and the weighted environmental impact values in Table XXXVII (Chapter VI, page 294). These relative values are combined to produce a single indicator of project feasibility from all three viewpoints.

Initial Weighting. Each curve is initially assigned identical weights of 10.0 before combining so that the procedure may be clearly demonstrated. Later in this section, the results of the 25 different possible weighting combinations involving maximum amplitudes of 3.0, 5.0, and 10.0 will be displayed as part of a sensitivity analysis.

Addition of the Indicators. Table XXXVIII adds the impact magnitudes of the economic, social, and environmental indicators derived in Chapters IV, V, and VI, for an interest rate of seven percent. Each of the three ES&E indicators receives equal weighting. Figure 11 shows the results of this process.

Since Chapter IV showed that the highest economic benefits for the project are accrued for the higher installed generating capacities,

TABLE XXXVIII

THREE GORGE PROJECT TOTAL RELATIVE IMPACT MAGNITUDE

Seven Percent Interest
Top of Conservation Pool Elevation Ten Meters Below Top of Dam
Bottom of Conservation Pool Elevation Thirty Meters Below Top of Dam

(Scale: 0.0 to 30.0)

Hydropower Installed Capacity (megawatts)		Elevations (meters)					
	TOD —>	100	110	120	130	140	150
	TOCP —>	90	100	110	120	130	140
	BOCP —>	70	80	90	100	110	120
1,000		2.88	4.28	9.99	11.33	10.97	10.32
2,000		3.00	4.50	10.34	11.92	11.57	10.97
3,000		3.04	4.55	10.51	12.19	11.91	11.57
4,000		3.03	4.59	10.62	12.37	12.10	12.01
5,000		2.99	4.62	10.72	12.48	12.21	12.40
6,000		2.95	4.63	10.82	12.60	12.33	12.76
7,000		2.97	4.70	10.98	12.77	12.62	13.14
8,000		3.00	4.78	11.04	12.96	12.86	13.51
9,000		3.01	4.86	11.12	13.13	13.07	13.82
10,000		3.04	4.94	11.17	13.32	13.28	14.08
11,000		3.03	5.00	11.25	13.46	13.49	14.32
12,000		3.03	5.04	11.32	13.60	13.68	14.56
13,000		3.03	5.10	11.39	13.75	13.87	14.86
14,300		3.03	5.18	11.43	13.93	14.11	15.20
15,600		3.05	5.24	11.47	14.12	14.35	15.53
18,200		3.11	5.40	11.59	14.52	14.79	16.03
20,800		3.18	5.52	11.65	14.65	15.21	16.47
23,400		3.25	5.63	11.64	14.71	15.54	16.88
25,000		3.30	5.71	11.58	14.69	15.73	16.93
27,000		3.25	5.71	11.59	14.72	15.82	17.03
29,000		3.22	5.67	11.58	14.74	15.85	17.09
31,000		3.15	5.61	11.57	14.74	15.83	17.12

The maximum net total benefits shown for any studied Three Gorge Reservoir configuration at an interest rate of seven percent is 17.12 for an installed hydropower capacity of 31,000 megawatts at a top of conservation pool elevation of 140 meters. Values within twenty percent of this number (13.70 and above) are outlined on this two-page table, and these project configurations might be studies in detail during a second- stage, or feasibility, investigation.

TABLE XXXVIII (continued)

EXAMPLE: ANNUALIZED THREE GORGE PROJECT NET ECONOMIC IMPACT MAGNITUDE

Seven Percent Interest
Top of Conservation Pool Elevation Ten Meters Below Top of Dam
Bottom of Conservation Pool Elevation Thirty Meters Below Top of Dam

(Scale: 0.0 to 10.0)

Hydropower Installed Capacity (megawatts)		Elevations (meters)					
	TOD -->	160	170	180	190	200	210
	TOCP -->	150	160	170	180	190	200
	BOCP -->	130	140	150	160	170	180
1,000		8.66	6.67	4.63	2.70	-2.95	-9.02
2,000		9.31	7.33	5.29	3.35	-2.30	-8.27
3,000		9.92	7.95	5.92	3.99	-1.67	-7.64
4,000		10.45	8.59	6.56	4.62	-1.02	-7.00
5,000		10.88	9.08	7.15	5.24	-0.39	-6.36
6,000		11.27	9.51	7.58	5.80	0.20	-5.73
7,000		11.71	9.96	8.02	6.30	0.86	-4.91
8,000		12.09	10.40	8.48	6.77	1.35	-4.32
9,000		12.44	10.79	8.90	7.23	1.81	-3.87
10,000		12.79	11.17	9.27	7.66	2.27	-3.47
11,000		13.03	11.46	9.59	7.98	2.63	-3.09
12,000		13.27	11.70	9.88	8.27	2.91	-2.66
13,000		13.51	11.96	10.16	8.56	3.27	-2.38
14,300		13.83	12.33	10.48	8.95	3.59	-2.00
15,600		14.09	12.74	10.80	9.28	3.98	-1.60
18,200		14.64	13.34	11.46	9.98	4.73	-0.80
20,800		15.13	13.86	12.02	10.58	5.36	0.13
23,400		15.56	14.33	12.51	11.10	5.91	0.45
25,000		15.64	14.61	12.81	11.41	6.24	0.79
27,000		15.78	14.77	13.03	11.66	6.51	1.06
29,000		15.89	14.87	13.13	11.80	6.65	1.22
31,000		15.92	14.92	13.16	11.87	6.70	1.29
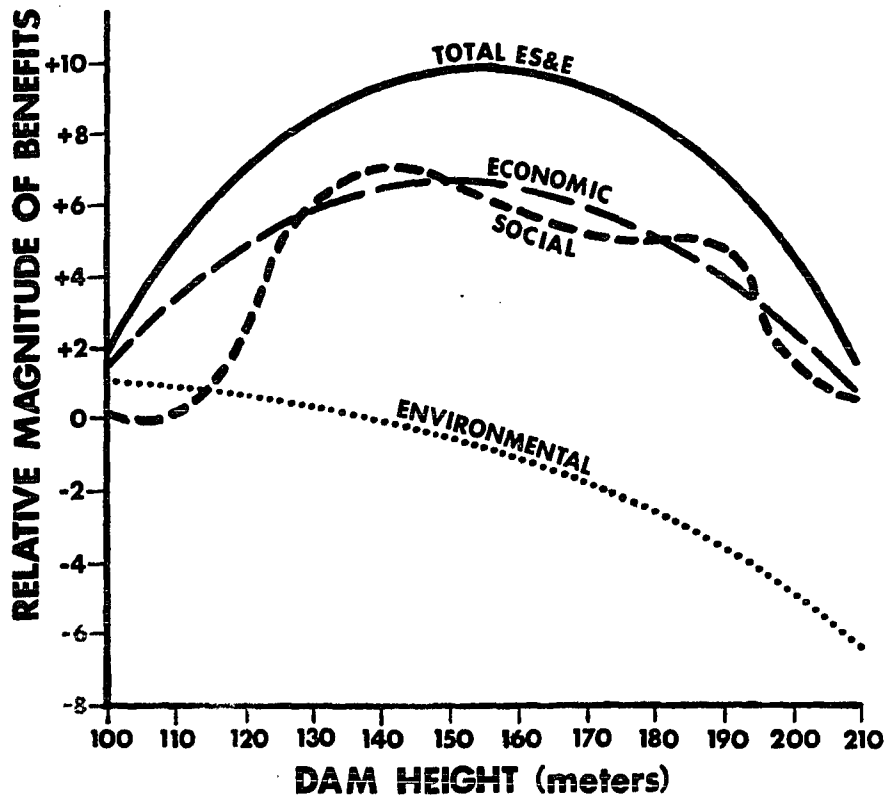
Figure 11. Summation of the economic, social, and environmental (ES&E) impact curves for the Three Gorge Dam and Reservoir. The ES&E curves are shown at two-thirds scale for clarity. The following parameters apply to all four curves shown above;

(1) The top of conservation pool elevation is ten meters below the top of dam height.
(2) The bottom of conservation pool elevation is thirty meters below the top of dam height.
(3) The prevailing interest rate is seven percent.
(4) The installed hydropower capacity is 27,000 megawatts.

only installed capacities of 18,200 megawatts and greater will be examined from this point onward, to avoid excessively long tables. All values are shown in Clowes (1987c).

The Sensitivity Test.

General. The above paragraphs demonstrate the procedure for adding the three indicators with equal weighting for an interest rate of seven percent only. It is extremely important to determine the effects that varying interest rates and weighting combinations upon the range of feasible project configurations. The following paragraphs describe a sensitivity test that fulfills this requirement.

Other Maximum Amplitudes. Table XXXIX shows the relative economic impact magnitude of the Three Gorge dam at interest rates of three, five, seven, and nine percent. These impacts are scaled to a maximum value of 10.0 for clarity.

This table shows that, from a purely economic standpoint, the top of dam height should be from 190 meters to 210 meters, depending upon interest rate. As described in Chapter IV, the optimum installed hydropower capacity is 25,000 megawatts at an interest rate of three percent, 27,000 megawatts at interest rates of five and seven percent, and 29,000 megawatts at an interest rate of nine percent.

Table XL shows these economic, social, and environmental impact indicators scaled to a maximum amplitude of 3.0, 5.0, and 10.0, so that the total impact curve may be based on various combinations for the sensitivity test. These maximum amplitudes are, of course, completely arbitrary, and mean that any indicator may be adjusted so that it has a relative magnitude of 3-1/3 times larger or three times smaller than

TABLE XXXIX

THREE GORGE PROJECT TOTAL NET ECONOMIC BENEFIT MAGNITUDE

(based upon a maximum value of 10.0)

Hydropower Installed Capacity (megawatts)	Top of Dam Elevation (meters)									
	120	130	140	150	160	170	180	190	200	210
Three Percent Interest										
18,200	3.21	3.92	4.56	6.35	6.57	7.18	7.29	7.69	7.91	8.13
20,800	3.46	4.21	4.88	6.71	6.97	7.61	7.76	8.19	8.45	8.70
23,400	3.52	4.47	5.17	7.03	7.31	7.98	8.16	8.62	8.91	9.18
25,000	3.52	4.51	5.35	7.23	7.52	8.20	8.39	8.87	9.16	9.45
27,000	3.54	4.50	5.51	7.39	7.70	8.39	8.59	9.08	9.39	9.69
29,000	3.55	4.49	5.64	7.46	7.79	8.51	8.75	9.24	9.55	9.87
31,000	3.54	4.46	5.68	7.49	7.84	8.57	8.81	9.35	9.68	10.00
Five Percent Interest										
18,200	3.28	4.37	4.98	6.71	6.88	7.42	7.48	7.85	7.93	7.97
20,800	3.34	4.54	5.36	7.13	7.32	7.91	8.00	8.41	8.52	8.60
23,400	3.33	4.61	5.67	7.50	7.74	8.34	8.45	8.89	9.03	9.14
25,000	3.29	4.61	5.86	7.74	7.86	8.59	8.73	9.17	9.32	9.44
27,000	3.28	4.64	5.98	7.83	7.98	8.74	8.96	9.40	9.58	9.71
29,000	3.27	4.64	6.03	7.87	8.05	8.83	9.09	9.54	9.75	9.90
31,000	3.24	4.63	6.04	7.88	7.69	8.86	9.15	9.62	9.84	10.00
Seven Percent Interest										
18,200	3.11	4.75	5.36	7.17	7.28	7.78	7.78	8.07	8.03	7.87
20,800	3.17	4.88	5.78	7.61	7.77	8.30	8.34	8.67	8.66	8.54
23,400	3.16	4.94	6.11	8.02	8.20	8.77	8.83	9.19	9.21	9.12
25,000	3.10	4.92	6.30	8.07	8.28	9.05	9.13	9.50	9.54	9.46
27,000	3.11	4.95	6.39	8.17	8.42	9.21	9.35	9.75	9.81	9.73
29,000	3.10	4.97	6.42	8.23	8.53	9.31	9.45	9.89	9.95	9.89
31,000	3.09	4.97	6.40	8.26	8.56	9.36	9.48	9.96	10.00	9.96
Nine Percent Interest										
18,200	3.12	4.71	5.57	8.08	7.46	7.91	7.84	8.06	7.80	7.55
20,800	3.12	4.81	5.97	8.13	7.99	8.48	8.45	8.71	8.49	8.27
23,400	3.00	3.93	6.27	7.80	8.21	8.98	8.99	9.28	9.08	8.90
25,000	2.91	3.89	6.45	7.81	8.27	9.07	9.19	9.63	9.46	9.32
27,000	2.91	3.91	6.52	7.89	8.38	9.21	9.35	9.82	9.70	9.58
29,000	2.89	3.91	6.52	7.93	8.44	9.28	9.41	9.94	9.81	9.71
31,000	2.87	3.91	6.47	7.95	8.48	9.31	9.41	10.00	9.84	9.74

TABLE XL

THREE GORGE PROJECT TOTAL NET ES&E
BENEFIT MAGNITUDES AT SEVEN PERCENT INTEREST

Hydropower Installed Capacity (megawatts)	Top of Dam Elevation (meters)									
	120	130	140	150	160	170	180	190	200	210

Economic Net Benefit Magnitude (Maximum Amplitude: 3.0)

	120	130	140	150	160	170	180	190	200	210
18,200	0.93	1.43	1.61	2.15	2.18	2.33	2.33	2.42	2.41	2.36
20,800	0.95	1.46	1.73	2.28	2.33	2.49	2.50	2.60	2.60	2.56
23,400	0.95	1.48	1.83	2.41	2.46	2.63	2.65	2.76	2.76	2.74
25,000	0.93	1.48	1.89	2.42	2.48	2.72	2.74	2.85	2.86	2.84
27,000	0.93	1.49	1.92	2.45	2.53	2.76	2.81	2.92	2.94	2.92
29,000	0.93	1.49	1.93	2.47	2.56	2.79	2.84	2.97	2.99	2.97
31,000	0.93	1.49	1.92	2.48	2.57	2.81	2.84	2.99	3.00	2.99

Economic Net Benefit Magnitude (Maximum Amplitude: 5.0)

	120	130	140	150	160	170	180	190	200	210
18,200	1.56	2.37	2.68	3.58	3.64	3.89	3.89	4.03	4.02	3.98
20,800	1.59	2.44	2.89	3.80	3.88	4.15	4.17	4.33	4.33	4.27
23,400	1.58	2.47	3.05	4.01	4.10	4.38	4.42	4.60	4.60	4.56
25,000	1.55	2.46	3.15	4.03	4.14	4.52	4.56	4.75	4.77	4.73
27,000	1.56	2.47	3.20	4.08	4.21	4.60	4.67	4.88	4.90	4.87
29,000	1.55	2.48	3.21	4.12	4.27	4.65	4.72	4.95	4.97	4.95
31,000	1.54	2.48	3.20	4.13	4.28	4.68	4.74	4.98	5.00	4.98

Economic Net Benefit Magnitude (Maximum Amplitude: 10.0)

	120	130	140	150	160	170	180	190	200	210
18,200	3.11	4.75	5.36	7.17	7.28	7.78	7.78	8.07	8.03	7.87
20,800	3.17	4.88	5.78	7.61	7.77	8.30	8.34	8.67	8.66	8.54
23,400	3.16	4.94	6.11	8.02	8.20	8.77	8.83	9.19	9.21	9.12
25,000	3.10	4.92	6.30	8.07	8.28	9.05	9.13	9.50	9.54	9.46
27,000	3.11	4.95	6.39	8.17	8.42	9.21	9.35	9.75	9.81	9.73
29,000	3.10	4.97	6.42	8.23	8.53	9.31	9.45	9.89	9.95	9.89
31,000	3.09	4.97	6.40	8.26	8.56	9.36	9.48	9.96	10.00	9.96

Social Net Benefit Magnitude (from TABLE XXXV)

	120	130	140	150	160	170	180	190	200	210
Amp: 3.0	2.34	2.95	3.00	2.98	2.78	2.55	2.35	2.28	1.32	0.41
Amp: 5.0	3.90	4.91	5.00	4.97	4.64	4.25	3.91	3.80	2.20	0.68
Amp: 10.0	7.79	9.82	10.00	9.94	9.28	8.51	7.82	7.60	4.39	1.36

Environmental Net Benefit Magnitude (from TABLE XXXVII)

	120	130	140	150	160	170	180	190	200	210
Amp: 3.0	0.26	0.05	-0.11	-0.26	-0.52	-0.83	-1.19	-1.66	-2.28	-3.00
Amp: 5.0	0.43	0.08	-0.17	-0.43	-0.86	-1.38	-1.98	-2.76	-3.80	-5.00
Amp: 10.0	0.86	0.17	-0.35	-0.86	-1.72	-2.76	-3.97	-5.52	-7.59	-10.00

any other indicator. Many other weighting combinations are possible.

It should be noted here that the Three Gorge project social and environmental net benefit magnitudes are assumed to be largely independent of the prevailing interest rate.

Table XLI shows the results of a sensitivity study for a project installed hydropower capacity of 27,000 megawatts at an interest rate of seven percent. The 25 combinations shown in the left-hand column represent all of the possible non-duplicating combinations of the ES&E indicators with relative weights of 3.0, 5.0, and 10.0.

Table XLII shows the results of several impacts weightings for interest rates of three, five, and nine percent. The remaining values are given in Clowes (1987c).

Conclusions.

Tables XLI and XLII show that the optimum dam height of 150 meters is virtually indpendent of interest rate or ES&E curve weighting. For an interest rate of seven percent, 22 of the 25 possible ES&E curve weightings result in an optimum dam height of 150 meters. In fact, the lowest rating that the 150 meter dam height receives is a 9.96, in the case of the 3/10/10 and 3/3/10 combinations. This value is insignificantly less than the maximum possible value of a perfect "10."

For the other interest rates, the results are almost as uniform. For interest rates of three, five, and nine percent, the 150 meter dam elevation receives the maximum score of 10.00 in 64 out of 75 cases. The minimum score for the 150 meter dam height in any combination for any interest rate is 9.67. The optimum dam height for any interest

TABLE XLI

THREE GORGE PROJECT NET TOTAL BENEFIT MAGNITUDES
FOR VARIOUS ES&E CURVE WEIGHTINGS

(seven percent interest, 27,000 megawatts installed capacity)

Weighting E/S/E	Top of Dam Elevation (meters)									
	120	130	140	150	160	170	180	190	200	210
10/10/10	6.81	8.64	9.29	10.00	9.27	8.67	7.65	6.85	3.82	0.62
10/10/ 5	6.39	8.38	9.16	10.00	9.53	9.25	8.60	8.26	5.90	3.47
10/ 5/10	6.39	8.15	8.54	10.00	9.24	8.72	7.56	6.52	3.58	0.33
5/10/10	7.76	9.46	9.76	10.00	8.94	7.85	6.45	5.25	1.24	-2.94
10/10/ 3	6.45	8.57	9.43	10.00	9.97	9.81	9.28	9.11	6.94	4.73
10/ 3/10	6.12	7.82	8.77	10.00	9.21	8.55	7.51	6.31	3.43	0.13
3/10/10	8.29	9.92	10.00	9.96	8.71	7.33	5.72	4.26	-0.32	-5.07
10/ 3/ 3	5.23	7.28	8.50	10.00	9.81	9.86	9.66	9.53	8.14	6.58
3/ 3/10	8.99	10.00	9.92	9.96	7.77	5.48	2.50	-0.83	-7.47	-14.88
3/10/ 3	7.40	9.35	9.73	10.00	9.31	8.61	7.78	7.30	4.16	1.05
10/ 5/ 5	5.83	7.80	8.82	10.00	9.60	9.36	8.88	8.49	6.47	4.29
5/ 5/10	7.71	9.21	9.58	10.00	8.70	7.43	5.59	3.80	-0.68	-5.52
5/10/ 5	7.19	9.09	9.58	10.00	9.30	8.63	7.73	7.14	4.03	0.90
5/ 3/10	7.67	8.99	9.41	10.00	8.65	7.07	4.89	2.59	-2.28	-7.70
3/ 5/10	8.67	9.99	10.00	9.99	8.28	6.44	4.12	1.72	-3.89	-9.92
5/10/ 3	6.97	8.95	9.51	10.00	9.43	8.93	8.22	7.87	5.10	2.36
3/10/ 5	7.65	9.51	9.82	10.00	9.16	8.26	7.22	6.47	2.92	-0.64
10/ 3/ 5	5.47	7.42	8.58	10.00	9.64	9.50	9.07	8.65	7.30	4.81
10/ 5/ 3	5.62	7.67	8.75	10.00	9.74	9.66	9.38	9.24	7.57	5.80
3/ 5/ 5	7.52	9.26	9.65	10.00	9.03	8.05	6.76	5.63	1.86	-2.04
5/ 3/ 5	6.51	8.27	9.07	10.00	9.24	8.71	7.60	6.62	3.64	0.41
5/ 5/ 3	6.49	8.43	9.19	10.00	9.48	9.14	8.41	7.98	5.48	2.93
5/ 3/ 3	6.10	8.01	8.93	10.00	9.51	9.30	8.58	8.09	5.80	3.37
3/ 5/ 3	7.09	8.99	9.50	10.00	9.29	8.64	7.72	7.05	3.97	0.84
3/ 3/ 5	7.39	9.01	9.47	10.00	8.89	7.65	6.34	4.84	0.87	-3.40
AVERAGES	6.95	8.73	9.32	10.00	9.19	8.44	7.33	6.35	3.10	-0.38

Figures are added and adjusted to a maximum value of 10.00.

TABLE XLII

THREE GORGE PROJECT NET TOTAL BENEFIT MAGNITUDES
FOR VARIOUS ES&E CURVE WEIGHTINGS

Weighting E/S/E	Top of Dam Elevation (meters)									
	120	130	140	150	160	170	180	190	200	210

Three Percent Interest

10/10/10	7.36	8.72	9.25	10.00	9.29	8.64	7.64	6.90	3.91	0.82
10/10/ 3	6.75	8.35	9.07	10.00	9.67	9.47	8.99	8.91	6.87	4.87
10/ 3/10	7.01	7.89	8.67	10.00	9.26	8.70	7.48	6.36	3.55	0.14
3/10/10	8.56	9.98	10.00	9.98	8.73	7.33	5.72	4.31	-0.26	-4.97
10/ 3/ 3	5.97	7.25	8.33	9.92	9.91	10.00	9.69	9.69	8.47	7.20
3/10/ 3	7.64	9.40	9.72	10.00	9.31	8.59	7.77	7.33	4.20	1.14
3/ 3/10	9.55	10.00	9.75	9.80	7.65	5.29	2.29	-0.96	-7.56	-14.78
AVERAGES	7.55	8.80	9.26	9.96	9.12	8.29	7.08	6.08	2.74	-0.80

Five Percent Interest

10/10/10	7.01	8.62	9.25	10.00	8.99	8.61	7.67	6.90	3.92	0.80
10/10/ 3	6.77	8.33	8.94	10.00	9.37	9.42	8.99	8.86	6.81	4.76
10/ 3/10	6.44	7.75	8.69	10.00	8.75	8.65	7.53	6.38	3.57	1.36
3/10/10	8.39	9.93	10.00	9.98	8.61	7.34	5.76	4.34	-0.21	-4.92
10/ 3/ 3	5.51	7.20	8.43	10.00	9.81	9.98	9.73	9.66	8.38	6.99
3/10/ 3	7.49	9.35	9.72	10.00	9.19	8.59	7.79	7.33	4.20	1.13
3/ 3/10	9.25	10.00	9.89	9.93	7.47	5.43	2.51	-0.78	-7.36	-12.51
AVERAGES	7.27	8.74	9.27	9.99	8.88	8.29	7.14	6.10	2.76	-0.34

Nine Percent Interest

10/10/10	6.77	8.16	9.47	10.00	9.42	8.84	7.79	7.09	3.90	0.65
10/10/ 3	5.90	7.82	9.28	10.00	9.78	9.64	9.10	9.04	6.78	4.59
10/ 3/10	6.03	6.98	9.06	10.00	9.47	9.04	7.74	6.71	3.55	0.15
3/10/10	8.21	9.63	10.00	9.90	8.71	7.37	5.76	4.38	-0.22	-4.94
10/ 3/ 3	4.96	6.27	8.49	9.67	9.74	10.00	9.78	9.63	8.05	6.48
3/10/ 3	7.38	9.15	9.80	10.00	9.36	8.67	7.83	7.41	4.19	1.06
3/ 3/10	8.85	9.35	10.00	9.83	7.84	5.62	2.61	-0.52	-7.23	-14.53
AVERAGES	6.87	8.19	9.44	9.91	9.19	8.45	7.23	6.25	2.72	-0.93

Installed hydropower capacities are 25,000 megawatts at an interest rate of three percent, 27,000 megawatts at interest rates of five and seven percent, and 29,000 megawatts at an interest rate of nine percent.

rate or any ES&E weighting combination does not exceed 170 meters or fall below 130 meters.

This nearly uniform result - which seems to contradict intuition and engineering and economic judgement - is due to the unique shape of the individual ES&E curves shown in Figure 11.

Three Gorge project economic net benefits increase very rapidly with dam height to an elevation of 150 meters, and then flatten out significantly. The social net impact curve is bell-shaped, and peaks sharply at 140 to 150 meters. The environmental net impact curve assumes a slightly downward slope from elevations of 90 meters to 140 meters, and then drops steeply as very large tracts of farmland are flooded.

Because of the shape of these curves, and due to the fact that the shapes of the social and environmental impact curves are independent of interest rate, it is inevitable that a dam height of about 150 meters would be the most feasible from a multiple-perspective outlook - but only if the large number of assumptions made in this study remain unchanged.

However, even radical changes in many of the most important assumptions underlying this study will not change the ultimate dam height significantly. The conclusions reached in this study are remarkably insensitive to changes in basic assumptions. This characteristic is explained in greater detail below.

Sensitivity to Changes in Economic Assumptions and Parameters.

Overview. The shape of the Three Gorge project economic impact curve is unlike to change significantly as underlying assumptions and

parameters change, because its several components are relatively insensitive to such changes. This means that the shape of the net economic benefits curve will assume a characteristic shape after weighting with a specified maximum amplitude, virtually independent of underlying assumptions.

Flood Control. The project's net flood control benefits are primarily based upon the direct benefits or costs related to three variables: permanent relocations, avoided net temporary relocations, and avoided farmland inundation.

These figures are founded upon firm hydrologic and demographic information that is unlikely to change significantly in the near future. The only possible significant change that could take place is the actual cost of relocating an urban or rural dweller. Even if this occurs, the shape of the net flood control benefit curve will remain approximately in its current form.

Hydropower. The Three Gorge project's economic impacts are dominated by hydropower benefits. As with every project the author has studied, incremental hydropower benefits, because of the shape of the generation-duration curve, increase swiftly for the first generating units installed, but decrease with each succeeding unit. Therefore, the shape of the curve which relates net hydropower benefits to dam height is founded upon the incremental energy generated. Although these benefits may change quite significantly when such factors as fuel cost escalation rates fluctuate, the shape of the net economic impact curve will tend to remain relatively stable after its relative weight has been assigned. in other words, since Three Gorge project net

economic benefits are heavily dependent upon hydropower benefits, the shape of the economic benefit curve will follow that of the hydropower benefit curve.

Other Benefits. Compared to flood control and hydropower, navigation and recreation exert a relatively small influence upon the shape of the net economic impact curve. Additionally, navigation benefits vary little with changes in dam height (see Table XXVI, Chapter IV), and recreation benefits remain constant regardless of dam height. Therefore, these 'minor' benefits exert little influence upon the ultimate shape of the net economic benefit curve.

Sensitivity to Changes in Social Assumptions and Parameters.

Overview. Figure B (Chapter V) shows the shape of the Three Gorge project social impact curve under the current assumptions of this study. Relative net benefits increase very steeply as the dam height rises from 100 meters to 140 meters, and peak at a dam height of about 150 meters. The net benefits then decline moderately as the dam height increases to 190 meters, and drop very steeply as the dam height increases to 210 meters.

The following paragraphs describe how changes in basic assumptions or critical data may affect the range of optimum dam heights from a social standpoint.

Relative Social Impact Weighting. The relative weightings of the project's social impacts are shown in Table XXXIII. For example, if the project's flood control operations save a life, they are credited with a relative magnitude of +15. If they save a temporary relocation,

they receive a credit of +1. A permanent relocation caused by reservoir filling is assigned a value of -2.

If the 'base' value of ± 1 is assigned to a temporary relocation, it is logical to assign a larger number to the impact of a permanent relocation, because the magnitude of the inconvenience and suffering imposed upon a person is greater. The magnitude assigned to permanent relocations is not present-worthed, because it is a one-time impact that occurs during project construction.

Weighting Assigned to Saved Lives. The greatest potential for changing the position of the 'peak' value in Figure B lies in the value given to the relative impact of saving a human life. However, although the shape of the net social impact curve will change somewhat with a change in the relative 'value' of a human life, the conclusion regarding the optimum dam height from the social standpoint remains virtually unchanged.

For example, if the relative value assigned to the saving of a life is changed from +15 to +5, and the discount rate assigned to future benefits remains at 1.5 percent, the optimum top of dam height for flood control remains at 140 meters. If the relative value assigned to the saving of a life is doubled to +30, the optimum top of dam height remains at 140 meters. The optimum top of dam height will shift only slightly if an extremely large relative value is assigned to the saving of a life (i.e., a value of +100 will shift the optimum top of dam height to 150 meters) (Clowes, 1987c).

Changes in the Discount Rate. The discount rate applied to future lives saved and avoided temporary relocations for this study was 1.5

percent, based upon opinions expressed by thirty Chinese engineers and scientists. If the weightings given to lives saved and temporary relocations avoided remain constant, a decrease in this interest rate will result in larger benefits relative to the costs incurred by necessary permanent relocations. This will tend to move the "peak" shown on Figure B very slightly to the left. For example, if the discount rate were decreased to 0.5 percent, the optimum dam height for net flood control benefits would change from 140 meters to about 137 meters.

If the discount rate is increased to five percent, the 'peak' of the curve is moved slightly to the right - to about 145 meters. The present worth of future benefits would be greatly decreased, and, since the value assigned to permanent relocations remains constant and is negative, all dam heights above 170 meters are rendered economically infeasible from the standpoint of flood control.

Any further increase in the discount rate would result in the present-worthed value of project flood control benefits becoming very small, and would result in a maximum optimum dam height of about 150 meters.

In summary, the discount rate does not significantly affect the selection of the optimum dam height for flood control.

Population Distribution. The Three Gorge project would primarily protect the several heavily populated downstream flood diversion areas described in Chapter IV. Although the Ministry of Water Resources and Electric Power has provided rather precise information on the total population of these areas, no data was available regarding the

distribution of this population within the flood diversion areas. Therefore, this study assumed a uniform population distribution.

The number of temporary relocations saved by project flood control operations would be relatively unaffected by a change in population distribution, because the flood diversion areas are completely flooded in any case, so all persons would need to be evacuated regardless of their distribution.

It is very difficult to predict how the number of lives saved would be changed by a population redistribution. Flood control benefits due to lives saved would probably be changed more by other factors. For example, if the flood diversion areas could be evacuated in a more timely manner due to improved communication, transportation, and warning systems, the number of lives lost in the without-project scenario would certainly decrease, leading to a decrease in flood control benefits due to lives saved. This loss in benefits might be partially offset by a relatively rapid increase in rural population due to an increase in standard of living and the difficulty of enforcing the central government's population control policies in areas far from the large cities.

Other Factors. This study bases net social benefits almost exclusively upon the effects of Three Gorge project flood control operations. Information on the possible impacts upon 'quality of life' of such project functions as irrigation, navigation, and hydropower is scarce or nonexistent. Therefore, the impact of these effects upon project net social benefits was not examined.

The greatest potential for such benefits would probably be attributable to rural electrification. This use of Three Gorge project power seems unlikely, because the Ministry of Water Resources and Electric Power has already dedicated the output of the project to large urban population and industry centers.

Sensitivity to Changes in Environmental Assumptions and Parameters.

Overview. The Three Gorge project net environmental impact curve can be affected in one of two ways; by changing the weights assigned to 'lump-sum' environmental impacts, or by changing the weights assigned to land inundation.

It is assumed, for the purposes of this study, that a certain cluster of impacts (microclimate effects, air quality improvements, etc). will retain a magnitude of +13 regardless of dam height. The derivation of this value is described in Chapter VI. It is not strictly true that this value will remain constant as dam height varies, of course. A very large installed capacity at the project could accrue twice the air quality benefits of a small installation, but these benefits would probably be partially or wholly offset by other undesirable effects brought on by the construction of a larger embankment.

The total net environmental impact of the project assumes a positive value at the lower dam heights, and, as the height of the dam increases, more and more incremental land area is flooded per ten-meter increase in the dam height, leading to a steeper downward slope in the curve.

The table below shows the changes in the shape of the net environmental impact curve that are caused by changes in the relative value assigned to farmland inundation. The value currently assigned to the inundation of 25 square kilometers of land is -1. Each value is scaled to a maximum negative total impact of -10.0.

Dam Height (meters)	Value assigned to the inundation of 25 square kilometers of farmland		
	-0.5	-1.0	-2.5
100	+4.90	+1.55	+0.21
110	+4.43	+1.21	-0.11
120	+3.95	+0.86	-0.44
130	+3.20	+0.17	-0.96
140	+2.44	-0.35	-1.48
150	+1.63	-0.86	-2.03
160	+0.70	-1.72	-2.67
170	-0.61	-2.76	-3.56
180	-2.27	-3.97	-4.70
190	-4.28	-5.52	-6.08
200	-6.75	-7.59	-7.77
210	-10.00	-10.00	-10.00

As the negative value assigned to the permanent inundation of a unit of farmland increases, total negative envirnomental impact naturally increases as well. However, since the maximum negative amplitude that is assigned to net environmental impacts is 10.0, the incremental differences in impact between dam heights change only slightly.

This means that the basic shape of the net environmental impact curve remains the same, and the total impact upon the total ES&E impact curve is slight. For example, if a value of -0.5 per 25 square kilometers of inundated farmland is assumed, the optimum dam height will change from 150 meters to about 148 meters. A value of -2.5 per

25 square kilometers of inundated farmland would lead to an optimum dam height of about 155 meters.

Summary of Conclusions.

It appears that the shapes of all three of the ES&E curves are remarkably insensitive to changes in a single basic assumption. However, many major assumptions have been outlined in this study, and it is quite possible that significant changes in several of these could lead to a radical change in the optimum dam height or reservoir configuration.

Most of the author's assumptions were made in order to fill in gaps in missing or unreliable information. If the Chinese government performs the studies recommended in this chapter, many of these assumptions could be replaced with hard data. This would result in a much more reliable assessment of the range of optimum Three Gorge project configurations.

THE SELECTION PROCESS

Introduction.

If the procedure described in this dissertation is used, the optimum configuration for any project will depend entirely upon the shape of the total ES&E benefits curve. The final shape of this curve is, in turn, dependent upon the shapes of the individual ES&E curves. And the shapes of these three curves rely upon the work done by the experts in the appropriate fields of discipline.

All four curves are based upon clusters of beneficial and detrimental project impacts. The study teams and decisionmakers must perform two levels of weighting when using this process. The first

level occurs when the three study teams assess the relative economic, social, and environmental impacts of a project <u>within</u> each category. The second level takes place when the decisionmaker(s) assess the importance of the three clusters of impacts relative to each other.

This section briefly describes how such a dual-level weighting process might occur.

<u>Weighting Within Categories</u>.

Because of the sheer volume of information available when dealing with a large project, the individual economic, social, and environmental studies will largely be performed by experts in their respective fields. These experts will be required to perform a very rigorous and complete evaluation of their areas of expertise while consulting freely with those working in other areas.

There will certainly be temptations to influence the decision regarding the ultimate project configuration by emphasizing the faults or advantages of a project, depending upon the study team's point of view. For example, the economic study team may attempt to assign inordinately large hydropower benefits to peak-loaded increments of Three Gorge project generation, thereby biasing the dam height in an upward direction. This may be wholly or partially offset by the environmental study team trying to influence the final decision in the other direction by assigning very large negative values to localized impacts in the immediate area of the project.

There are three methods by which the influences of such manipulation may be reduced. To begin with, each of the three ES&E teams would not be allowed to develop their conclusions in a vacuum.

Authorities in each general field would be permanently assigned to each of the three teams. This hopefully would insure that the perspectives of the teams did not become excessively ingrown or provincial.

Secondly, an interdisciplinary audit team could be assigned to monitor the efforts of the three basic study teams. This audit team would be charged with insuring proper documentation of all data and assumptions. They would also facilitate free communication between teams.

The final safeguard is the decisionmaking body itself. This group would reserve the right to assign final weightings between categories to themselves. One possible permutation of this final weighting process is described below.

Weighting Between Categories: The Courtroom Approach.

It is naive to expect that any decision regarding an important project will be made without prejudice or bias. A 'perfect' decision-maker might be a person who would be introduced into the world from an environment totally free of any information that might exert a prior influence on his or her decision regarding a project in any direction.

Such persons do not exist in reality. However, it may yet be possible to present the arguments of the study teams in a format not unlike that found in a courtroom situation, which is one of the most efficient means of presenting information in such a manner that relatively impartial decisions may be made.

The judge and jury in the case of the Three Gorge project might be the Standing Committee, consisting of General Secretary Zhao Ziyang, hydroelectric specialist Li Peng, Politburo members Qiao Shi and Hu

Qili, and Yao Yilin (Tyson). Such a distinguished jury might be appropriate for deciding the fate of a project with the stature and impact of the Three Gorge Dam and Reservoir.

Each study team might be allowed a couple of hours for opening arguments, a day to present their findings in a clear and concise manner, a day for cross-examination by members of the other team and by the Standing Committee, and a couple of hours for closing arguments and summaries. Entities that would be affected by the project might also be allowed to testify for a limited period of time. In the case of the Three Gorge project, such entities might include Sichuan Province; Wanxian, Wuhan, and Chongqing Cities; navigation and industrial concerns; representatives of the World Bank and Asian Development Bank; foreign experts; authorities on economics, sociology, and environmental matters who were not included on the study teams; and individuals who would be permanently relocated.

The Standing Committee could then deliberate at length - with testifying authorities available for clarification and consultation - and would then assign their personal weights to each of the three ES&E categories. These weights would depend strongly on the individual background of each member, and might be averaged at the end of the deliberations to yield a final weighting and therefore a final project configuration.

This process is naturally prey to all of the shortcomings of any other decisionmaking procedure. Infighting, turf battles, compromise, and unseen deals and prejudices would surely affect the final outcome. However, the courtroom simile, if carried out in a public forum, would

be conducive to the most impartial decisionmaking atmosphere that could reasonably be expected whenever human beings are involved.

This, of course, is only a suggested scenario. It is extremely unlikely that the Chinese government will abandon or significantly alter its extraordinarily complicated decisionmaking process, which consists primarily of incremental 'give and take' on many levels. The procedure described above is merely the author's concept of how the decisionmaking process might be carried out while allowing each perspective to be adequately represented and while minimizing those influences that lead to irrational or destructive results.

RECOMMENDATIONS

Summary.

Due to the limited resources available to the author, this study sets forth an approximate treatment of the benefits and costs of the Three Gorge Dam and Reservoir. However, time may show that the conclusions reached here fall within the range of actual experienced project benefits. Only a fully-informed interdisciplinary study team with long experience will be able to perform a proper study of such a large project. In order for the conclusions reached in this chapter to be properly confirmed or refuted, the Ministry of Water Resources and Electric Power and other appropriate government agencies should perform the studies outlined in the following paragraphs.

Flood Control.

New Development. The construction of the Three Gorge Reservoir will afford a much greater degree of protection to downstream areas than is now enjoyed. The Ministry of Water Resources and Electric

Power should determine if this protection will be of such a magnitude that one or more of the large downstream flood diversion areas may be opened up for industrial development, and what secondary benefits and costs will result from the resulting increase in production.

Upstream Development. Possible and probable upstream Yangtze River water resources development should be inventoried. Coordinated construction of several large headwater or mainstem projects with significant amounts of floodwater and conservation storage could decrease Three Gorge project flood control benefits while increasing the its hydropower benefits significantly.

Historical Resources. The great archeological and cultural resources of the Three Gorges should be surveyed. The total cost of this survey must be included in the overall project budget. Tourist's appreciation of Chinese history would be greatly enhanced by a display of these artifacts at a visitor's center.

Floodwalls. The possibility of installing floodwalls to protect low-lying areas of Wanxian and Chongqing should be investigated. The economic feasibility of floodwalls is an especially pressing question at higher normal reservoir elevations, because overall project permanent relocations costs mount very quickly above a normal reservoir water surface elevation in excess of 180 meters due to concentrated costs in Chongqing (see Figure 3 in Chapter III). Indeed, the primary objection to the higher reservoir elevations has historically been excessive relocations costs in Chongqing. Floodwalls, if feasible, could lend an entirely new dimension to the debate if they prevent significant permanent relocations relative to their overall cost.

Project Security. The huge Three Gorge project will be a tempting target in time of warfare. The government of the People's Republic of China should investigate the various defenses required to protect the dam from air attack (to include cruise missiles), and from conventional ground attack (to include infiltration and sabotage by such units as the Soviet Union's Spetnatz, or Special Forces). The government should study the possibility of backing up the project's electronic control systems with mechanical systems, because the former are vulnerable to EMP (electromagnetic pulse). Of course, the costs of defending against such attacks, including the salaries of Army security personnel, is a real cost and should be added to total project prices, possibly as a joint-use cost.

As a critical portion of this study, the Chinese government should use advanced dambreak programs to determine exactly what magnitude of damage would be caused downstream by a catastrophic event, and what protection could be provided in such a contingency, including attenuation of the dambreak flow by Gezhouba Reservoir pondage.

Lifesaving. The flood control operations of the Three Gorge project will save thousands of lives annually. The Chinese government should establish a methodology for evaluating this benefit. However, there is the possibility that, because of the uncertainties involved, the government will not wish to quantify this benefit, or would not address it even if it could be assigned a definite value.

Quality of Life. Obviously, the Three Gorge Dam and Reservoir will contribute immeasurably to the 'quality of life' of millions of peasants downstream, most of whom will no longer live in the shadow of

recurring Yangtze River floods that destroy their few possessions and ruin their crops. This is another very difficult problem in quantification that the Chinese government must either choose to discount or quantify rigorously.

Cost Allocation. Chapter IV shows that all project purposes will probably be capable of supporting themselves with revenues or benefits accrued from their portion of project operation. Still, a cost allocation for each possible reservoir configuration should be performed in order to determine for certain if project purposes other than flood control can be economically supported. This assessment would be particularly important at higher interest rates for those project purposes which will not return significant benefits for a longer period of time (i.e., irrigation).

The separable costs-remaining benefits (SCRB) method of cost allocation is described in Appendix C.

Reservoir Levels. This study examined a top of conservation pool that was ten meters below the top of dam, due to the fact that incremental gained hydropower benefits more than offset losses in flood control net benefits due to a decrease in flood storage space. The Yangtze Valley Planning Office should examine different top of conservation pool elevations relative to the top of dam. It might be possible to retain the current top of conservation pool elevation while saving on civil works by lowering the top of dam height. Alternatively, the current top of dam height might be retained while using a higher top of conservation pool elevation in order to gain further hydropower benefits.

Sediment Accumulation. Over the first eighty years of reservoir operation, the total storage space of the approved reservoir configuration will decrease by 11.1 cubic kilometers due to sediment accumulation. The great majority of this sedimentation will take place below the bottom of the conservation pool elevation, which, at 135 meters, has 12.5 cubic kilometers of capacity. The YVPO should determine what effect this will have upon flood control operations, and account for this effect (if any) in the benefit calculations.

Downstream Channel Scour. The Three Gorge Reservoir, by retaining large quantities of sediment, will cause scour in the downstream Yangtze channel. The probable effects of this channel degradation should be investigated. Scour caused by the discharge of 'cleaner' water from the reservoir may eventually lead to channel degradation between the existing main levees, thereby reducing maintenance costs, which should be calculated and credited to the project. This channel degradation may increase floodwater transmission capacity downstream to a level above the current 56,700 cubic meters per second, and this increase may be substantial and creditable to Three Gorge project flood control benefits. If channel degradation occurs as far downstream as the Shanghai area, it may reduce dredging requirements in the heavily-industrialized lower channel, and these reduced costs should be credited to the project. Alternatively, if the channel scours in the few hundred kilometers of river downstream of the Three Gorge and Gezhouba Dams, significant amounts of sediment may be carried to the estuary, worsening the navigation situation in the Shanghai area. The incremental costs of dredging due to this additional sediment, should

it be deposited, must be assessed to the Three Gorge project. Finally, the YVPO should carefully evaluate the specific effects of this 'cleaner' water on downstream fish species such as the Yangtze River Sturgeon.

Hydropower.

Turbine Size Combinations. The possibility of combining different turbine sizes should be investigated. Perhaps large turbines at world state-of-the-art level (700 to 800 megawatts) could be operated in a near-continuous baseload level, thereby increasing reliability and decreasing operation and maintenance (O&M) costs. Smaller turbines, in the 250 to 400 megawatt range, which are more reliable when cycled frequently, could be used to follow loads.

Production Cost Models. Numerous hourly production cost models, such as the Corps' POWRSYM and the Bureau of Reclamation's SAGE, are capable of simulating the operation of large hydro-thermal power systems. These models are extremely data-intensive, and require a relatively long running time on advanced computer systems. However, they allow a revealing look at how a power system will most efficiently operate both with and without the addition of a large thermal or hydro plant. The hourly production cost models mentioned above would be ideal for pinpointing the exact benefits that will accrue to the addition of any Three Gorge project energy and capacity to the Central and Eastern China power systems.

Underground Powerhouses. This study has shown that extremely large installed hydropower capacities are economically feasible at the Three Gorge project. The possibility of installing smaller turbines in

three, four, or even five underground powerhouses should be studied. In general, turbine-generator units in the 400 megawatt range and above incur extremely heavy operation and maintenance costs (Clowes, 1987b). Additionally, the loss of a very large turbine can have serious impacts upon power system stability. Although the construction of underground powerhouses may be more expensive initially, mechanical operation and maintenance costs for, say, fifty 260-megawatt units would be less than for twenty-six 500-megawatt units, and the smaller units would contribute more to project generating flexibility and reliability. Also, underground powerhouse layout would not be restricted to a certain narrow range of configurations due to a lack of space. Finally, underground powerhouses are certainly more attractive from a security standpoint.

Environmental Benefits. The environmental benefits of the enormous increment of Three Gorge hydropower, if any, remain almost completely unquantified, to include benefits to human health and air quality. These substantial benefits must be properly evaluated, quantified, and credited to the project.

Energy Displacement. The Chinese government should determine exactly how much coal-fired generation the Three Gorge project will displace. Also, great secondary benefits will be reaped from relieving pressure on the country's overtaxed railroad system, and from conserving the country's fossil fuels.

Secondary Benefits. China's heavy industry is losing tens of billions of dollars of productivity benefits annually due to lack of power. If the role of the Three Gorge project is primarily to add

completely new energy to the system, the MWREP should determine what secondary benefits may be claimed in terms of increased production and industry reliability.

This may be the most important question of all regarding Three Gorge project economic feasibility. If secondary benefits are shown to be equal or greater than primary hydro benefits, it will become more tempting to install as much capacity as possible at Three Gorge Dam.

Transmission Systems. This study has assumed that the transmission system that will distribute Three Gorge project energy will cost approximately as much as the system that would distribute alternative fossil-fuel energy in the without-project system. The Chinese government must eventually quantify the actual differences in costs between the with-project and without-project transmission systems. Depending upon the differences in costs, these may be a significant Three Gorge project benefit or cost.

Enhanced Gezhouba Power Benefits. The Three Gorge Reservoir will be capable of regulating the large flows of the Yangtze River for power operation. This operation will certainly allow the downstream 2,715 megawatt Gezhouba powerhouses to produce more power by reducing spillage, and will also increase the value of Gezhouba's capacity and energy. The YVPO should determine the magnitude of these benefits, and the percentage thay may be assigned to the Three Gorge Dam.
Navigation.

The Without-Project Navigation System. As with all benefit calculations, the actual project benefit is equivalent to the difference in annual costs between the with-rpoject navigation system

and the without-project navigation system. In the absence of the Three Gorge project, it will be necessary to construct large overland highways and railroads of sufficient capacity to carry the ultimate annual expected cargo volume of 50 million tons between Yichang and Chongqing. The Ministry of Communications should determine what the actual annual costs of the without-project navigation system will be, based upon an evaluation of several alternatives.

The Without-Project Navigation Volume. In the absence of the Three Gorge project, it is reasonable to assume that the ultimate annual volume of cargo between Yichang and Chongqing may be far less than 50 million tons. The primary and secondary benefits foregone due to the lower volume of cargo should be evaluated and counted as a benefit for the Three Gorge project.

Downstream Channel - Fuel Saved. Three Gorge Dam and Reservoir will be capable of substantially augmenting low flows for downstream navigation. The Chinese government should determine the magnitude of these benefits, primarily in terms of fuel saved.

Irrigation.

Low-Flow Augmentation. The Three Gorge Reservoir will be capable of significantly augmenting annual Yangtze River low flows. Under current conditions, salt intrusion into important agricultural areas is abated at a river flow of approximately 16,000 cubic meters per second. The Yangtze Valley Planning Office should evaluate what benefits (particularly in the area of the Yangtze Delta) will accrue to existing agriculture from this avoided salt intrusion.

North-South Water Transfer. The Chinese government should evaluate the benefits that will accrue to future agriculture if the construction of the Three Gorge project makes large-scale downstream South-North water transfer possible. These benefits, primarily in the form of increased production, could be prodigious. However, if the prevailing interest rate is relatively high, and if these benefits would not be reaped for a period of more than thirty years, their present worth would be small or negligible.

Recreation.

Foreign Exchange. The expected large increase in foreign visitors caused by the construction of Three Gorge Dam will naturally exert a favorable influence on China's foreign exchange situation. The magnitude of this impact should be evaluated.

Facilities. By adding another landmark to this area, The Three Gorge Dam and Reservoir will attract many domestic and foreign visitors on its own merits. The area will have the potential to be a truly outstanding tourist attraction, despite its relatively remote location. The possibilities of insuring easier access to the wild Gorges are almost endless, as are the costs. Perhaps the government will go so far as to construct an international airport at Yichang, with shuttles from Beijing, Shanghai and Hong Kong. They may construct modern highways and excellent trekking trails in the area. The costs of such projects would be huge, but might be offset by the resulting economic benefits to the national government. The possibilities mentioned above, and many others, should be investigated.

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APPENDIX A

TRACING THE COURSE OF THE YANGTZE RIVER

And everything shall lie whither the river cometh.
— Ezekiel 47:9

INTRODUCTION

Physical Dimensions of the River.

The People's Republic of China, the world's most populous country, has throughout its long history depended heavily upon its extensive river system – and in particular on the Yangtze River – for irrigation, transportation, and water supply.

The Yangtze (Chang Jiang, or "Long River") is the largest river in Asia. Measuring nearly 6,400 kilometers in length, it is the third longest river in the world, after the Amazon and the Nile. It drains an area of more than 1.8 million square kilometers (one-fifth of the land area of China), and is joined by more than 700 major tributaries before it empties into the East China Sea. Its average annual flow at Shanghai is more than 31,000 cubic meters per second (CMS), or more than twenty times the volume of China's second largest river, the Yellow, or Huang He (Liu).

Hydropower Potential.

The total surface runoff of all the rivers in China is about 2,600 cubic kilometers annually. The exploitable hydropower potential of

these rivers is approximately 378,000 megawatts (Shi, Jiayang). This means that China has more hydropower potential than any other country in the world. It is possible that the Yangtze River basin could be eventually developed for more than 197,000 megawatts of hydropower, which is more potential than all of the rivers in North America combined. The river and its tributaries could ultimately generate more than a billion megawatt-hours of electrical energy each year if fully developed. Table XLIII lists the length, drainage area, and average flows of the Yangtze River, its tributaries, and other major Chinese rivers.

Currently, only about five percent of the Yangtze's hydropower potential has been exploited. However, the Chinese government is planning an ambitious program of large hydro cascades on the main stem of the Yangtze and on its major tributaries. This network of existing and planned hydropower plants is shown in Figure 12, and information corresponding to these plants is shown in Table XLIV.

Irrigation Along the Yangtze.

China has relatively little arable land to support its huge population. Only about one-eighth of its total area, or about 1.07 million square kilometers, are currently under cultivation (Nickum). About one-fourth of this productive land lies in the lower Yangtze valley. In the last three decades, forty thousand reservoirs with a total storage capacity of one hundred billion cubic meters have been constructed in the Yangtze basin. These reservoirs serve most of the 130,000 square kilometers of irrigated farmland in the lower Yangtze plain (Biswas, 1983).

TABLE XLIII

BASIC HYDROLOGIC CHARACTERISTICS OF MAJOR RIVERS
IN THE PEOPLE'S REPUBLIC OF CHINA

Tributary	Station	Length Upstream of Station (kilometers)	Drainage Area (square kilometers)	Average Flow at Station (CMS)
YANGTZE RIVER				
Jinsha	Pingshan	2,650	485,099	4,520
Main Stem	Zhutuo	3,520	694,725	8,580
Main stem	Cuntan	3,820	866,559	11,090
Main stem	Wanxian	4,148	974,881	13,350
Main stem	Yichang	4,469	1,005,501	13,950
Main stem	mouth	6,300	1,803,500	30,442
YANGTZE RIVER TRIBUTARIES				
Yalong	mouth	1,187	144,280	1,910
Min	mouth	793	135,378	2,790
Jialing	mouth	1,119	156,142	2,200
Wu	mouth	1,018	88,220	1,750
Yuan	mouth	993	89,960	2,460
Tuo	Leechiawan	550	23,283	410
Xiang	mouth	811	92,500	2,400
Qing	Banyuzui	263	15,563	235
Han	mouth	1,532	174,350	1,690
Gan	mouth	758	81,660	2,590
OTHER MAJOR CHINESE RIVERS				
Yellow	mouth	5,464	752,443	1,496
Pearl	mouth	2,210	442,585	10,722
Huai	mouth	1,000	188,924	1,451
Hai	mouth	1,090	264,617	688
Songhua	mouth	2,002	545,596	2,464
Yalutsangpo	mouth	2,057*	240,480*	3,395
Lancan (upper Mekong)	mouth	2,354*	164,766*	1,686

* - portion of river flowing through China
References: Bonavia, Judy; MWREP, 1983b; and Cheng.
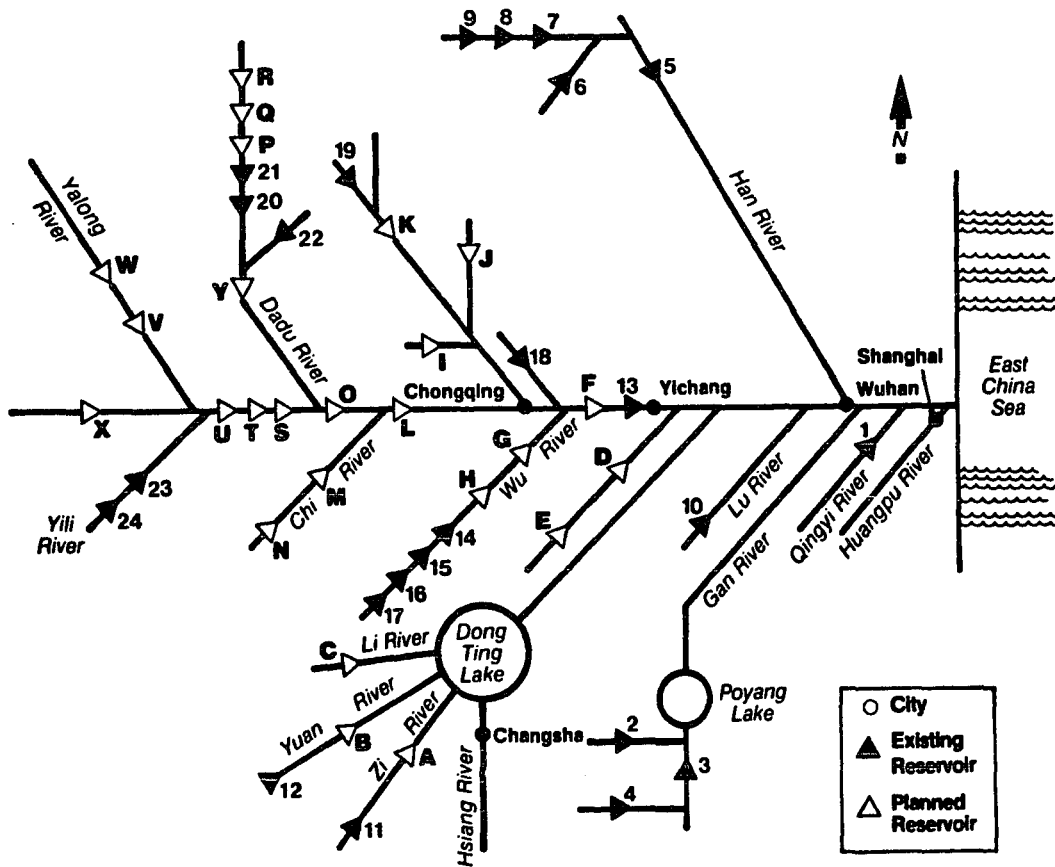
KEY

1. Chencun	7. Ankang	13. Gezhouba	19. Bikou
2. Wan'an	8. Shiquan	14. Wujiangdu	20. Gongzui
3. Dongjiang	9. Shimen	15. Hongyan	21. Tongjiezi
4. Zhalin	10. Lushui	16. Zhaixiangkou	22. Xingwenling
5. Danjiangkou	11. Zhaxi	17. Xiuwen	23. Yili Cascade
6. Huanglongtan	12. Fengtan	18. Shizitan	24. Maojiacun

A. Fuxikou	G. Pangshui	M. Lintan	R. Manai	V. Ertan
B. Zaoshi	H. Goupitan	N. Mozitang	S. Xiangjiaba	W. Jinping
D. Gehuyan #1	I. Wudu	O. Shipeng	T. Xilodou	X. Hutiaoxia
E. Gehuyan #2	J. Fengtan	P. Pubugou	U. Baihetan	Y. Pianchuangzi
F. Three Gorge	L. Zhuyangxi	Q. Dagangshan		

Figure 12. Schematic diagram of existing and planned multiple-purpose reservoirs on the Yangtze River and its major tributaries

TABLE XLIV

MAJOR EXISTING AND PLANNED YANGTZE RIVER HYDROPOWER PROJECTS

EXISTING PROJECTS

					Hydropower	
Number*	Project Name	River	Average Discharge (CMS)	Average Head (meters)	Installed Capacity (megawatts)	Annual Energy (TWh)
1.	Chencun	Qingyi	88	56	150	0.27
2.	Wan'an **	Gan	947	32	400	1.50
3.	Dongjiang **	Ou	220	135	300	1.32
4.	Zhalin	Xiu	250	37	180	0.49
5.	Danjiangkou	Han	1,230	82	900	3.88
6.	Huanglongtan	Du	194	85	150	0.77
7.	Ankang **	Han	608	88	800	2.80
8.	Shiquan	Han	372	46	135	0.91
9.	Shimen	Bao	44	65	40	0.17
10.	Lushui	Lu	86	33	35	0.13
11.	Zhaxi	Zi	621	74	448	2.29
12.	Fengtan	You	499	91	400	2.08
13.	Gezhouba **	Yangtze	14,300	27	2,715	13.90
14.	Wujiangdu	Wu	502	134	630	2.34
15.	Hongyan	Maotiao	49	45	30	0.18
16.	Zhaixiangkou	Maotiao	45	39	45	0.11
17.	Xiuwen	Maotiao	66	44	20	0.17
18.	Shizitan	Longxi	45	35	48	0.13
19.	Bikou	Bailong	275	86	300	1.46
20.	Gongzui	Dadu	1,500	53	700	3.42
21.	Tongjiezi **	Dadu	1,500	40	600	3.21
22.	Xingwenling	Min	880	77	400	3.55
23.	Yili Cascade	Yili	---	---	322	0.95
24.	Maojiacun	Yili	16	62	16	0.08
	Other Reservoirs		---	---	900	4.00
	TOTALS				10,664	50.01

PLANNED PROJECTS

A. Fuxikou   G. Pangshui   M. Lintan   R. Manai   V. Ertan
B. Zaoshi   H. Goupitan   N. Mozitang   S. Xiangjiaba   W. Jinping
D. Gehuyan #1   I. Wudu   O. Shipeng   T. Xilodou   X. Hutiaoxia
E. Gehuyan #2   J. Fengtan   P. Pubugou   U. Baihetan   Y. Pianchuangzi
F. Three Gorge   L. Zhuyangxi   Q. Dagangshan

* Numbers and letters correspond to those on Figure 11.
** Under construction.
    References: Cheng; ENR, 1984; Hangzhou; IWP+DC, 1981a and 1981b;
                 MWREP, 1983a and 1986; and Wu.

These plains produce forty percent of the grain products grown in China, including seventy percent of all paddy-grown rice and one-third of the national production of cotton. Other products include 48 percent of China's freshwater fish and forty percent of its industrial production value (Bonavia, Judy).

The People of the Plains.

More than 350 million people live in the lower Yangtze plains. Many of China's largest cities are located in this area, including Chongqing, Wuhan, Nanjing, Zhenziang, and Shanghai (CPH). These and other cities support the heaviest concentration of China's heavy industry, which consumes most of its electrical energy output. To date, coal and oil have been shipped from the North at great expense, but the Chinese have always kept in mind that the Yangtze can be the power behind the drive towards fulfilling the "Four Modernizations" by the year 2000.

This appendix follows the course of the Yangtze from its origin as a tiny braided stream in a glacier field to its enormous delta more than six thousand kilometers downstream.

THE UPPER REACHES OF THE RIVER

The Source of the Yangtze.

The Yangtze River begins its journey to the East China Sea on the glaciated southwest slope of 6,621 meter Geladandong Peak, among the wild Tanggula Mountains. This area is so remote and rugged that the river's source was not accurately charted until 1976.

The first of its many names is the Tuotuo River, a frigid, braided stream which is one of many originating in a permanent icefield of

about 600 square kilometers (Liu). The stream meanders through high marshlands for 210 kilometers before joining the Damqu River near Nangjibalong, to become the Tongtian River.

The Tongtian Reach.

The Tongtian flows 813 kilometers through the Yushu Tibetan Autonomous Region in broad, high valleys. The stream is shallow, sluggish and laced with many sandbars, and its flat banks are covered with thick grass, which provides an important summer grazing ground for yaks, antelope, and wild asses. Wheat and gingke barley grow in terraces near the river. At one point, the Tongtian River loses 915 meters in elevation over a reach of only 80 kilometers. 1,022 kilometers from its source, the river flows through Baitang, in Qinghai Province, near the town of Yushu ("Jade Trees"), so named because the people at one time considered trees more precious than jade (MWREP, 1983a).

The Jinsha Reach.

From Yushu, the Yangtze assumes the name Jinsha (Golden Sand) River, which runs south and east 2,308 kilometers to Yibin County in Sichuan (Schezuan) Province. The Jinsha drains about 520,000 square kilometers of the Chinese central highland, and accounts for 49 percent of the Yangtze River's total exploitable hydropower potential.

The Dadu River, a major tributary of the Jinsha, drops 1,800 meters of elevation over its lowest reaches, and averages 1,570 CMS of flow at its confluence with the main stem. This river will eventually be developed with a cascade of hydro plants having an installed

capacity of 19,200 megawatts, which will be good for 93,700 gigawatt-hours of generation annually.

When the Jinsha reaches the village of Shigu ("Stone Drum") in northwest Yunan Province, it forms a sweeping loop known as the "First Bend of the Yangtze." Thirty kilometers downstream of the polished marble drum for which the town was named, the Jinsha rushes through the famous Tiger's Leap Canyon (Hutiaoxia Gorge), which carves a course through the Yulong and Zhongdian Mountains. The river plunges 200 meters in seven rapids over a distance of just 16 kilometers, yielding the possibility of a hydro plant of as large as 15,000 megawatts installed capacity.

The Jinsha continues to drop steeply as it winds through the highlands of Sichuan and Yunnan Provinces. From about 27 degrees north latitude, the river forms the border between these two provinces for about 800 kilometers.

The largest tributary of the Jinsha is the Yalong River, which averages 1,910 CMS of flow at its mouth. Plans call for a cascade of plants with an installed capacity of 19,600 megawatts, which will generate 126,000 gigawatt-hours annually (Cao).

By the time it reaches its confluence with the Min River at the city of Yibin (Ipin), the Jinsha has a mean water elevation of only 258 meters, having dropped 3,300 meters of elevation since flowing through Shigu town. This reach of the Yangtze River may one day be the site of what will ultimately be the world's largest cascade hydro system, with an installed capacity of 49,000 megawatts, which will yield an average of 126,000 gigawatt-hours of electrical generation annually (Cao).

The Min River has the largest flow and hydropower potential of any of the Yangtze's tributaries. The extensive Dujiangyan irrigation system, near the city of Guanxian, was constructed around 250 B.C., and has been expanded through the centuries, currently watering more than 400,000 hectares in the Chengdu Plain (Liu).

The Chuanjiang Reach.

Overview. From its the town of Yibin to Yichang in Hubei Province, the river runs a thousand kilometers under the name of Chuanjiang. Most of this reach flows through Sichuan province, which means "Four Streams," referring to the large tributaries that join the Chuanjiang in this reach - the Min, Tuo, Jialing, and Wu. Sichuan Province, with warm winters and abundant rainfall, is one of the breadbaskets of China (Liu).

Chongqing. Chongqing, the "Misty City" and industrial center of southwest China, stands on rocky, hilly ground at the confluence of the Yangtze and Jialing Rivers. Along with Wuhan and Nanjing, it is known as one of China's "Three Furnaces," due to its hot, humid summers (Bonavia, Judy). The city today has a population of more than ten million, and some sources hold that it is the largest in China. It became the national capital in 1939, during the Sino-Japanese War, and remained such until liberation in 1949. Its principal industries are metals processing, coal, power, chemicals, textiles, machinery building, and electronics (CPH, 1983b).

The Wu River. About 110 river kilometers below Chongqing, the Yangtze is joined by the Wu River near the city of Fuling. The Wu, carving a sinuous course through steep valleys, has an exploitable

hydropower potential of more than 8,000 megawatts. Initial plans call for a 5,300 megawatt series of projects on the Wu river, which will generate about 27 terawatt-hours of energy annually (Cao). Recent dredging work has opened this river to navigation for a distance of 500 kilometers upstream of Fuling, linking Sichuan and northern Guizhou Province (Liu). Fuling is the connecting link in water transportation between North Guizhou Province and East Sichuan Province, and its products include grain, lacquer, and tung oil (Bonavia, Judy).

THE THREE GORGES

Introduction.

The 204-kilometer long section of the Yangtze River that stretches between the cities of Kuimen and Yichang forms the Three Gorges: Qutang, Wuxia, and Xiling. The river drops about 120 meters in elevation in the reach between Chongqing and Yichang. This large drop in elevation, combined with the river's huge flow, make the downstream mouth of the Three Gorges an ideal site for large hydropower development.

The Qutang Gorge.

The upstream Qutang (Wind Box) Gorge, referred to as the "Kuimen Gateway," is the strategic river passage between Sichuan and Hubei Provinces. Its entrance is guarded by the Chija Shan (Red Passage) Mountain on the north shore and the Baiyan Shan (White Salt) Mountain on the south. This gorge is only eight kilometers long and is the narrowest and most spectacular of the three, with the river's huge flow squeezing between walls which are, at their widest, only 150 meters apart. Some idea of the gorge's rugged topography is conveyed by

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Figure 13. Yangtze river depth may change more than 60 meters in a matter of days, and the curious sight of large steamers stranded on rocks thirty meters above the river's surface is not uncommon (ENR, 1984).

Wanxian City, with a population of about half a million, is located near the upper end of this gorge. Primarily because of its strategic position, it is known as the "Gatway to East Sichuan." Its industries include silkworm culturing, silk spinning, teas, bamboo, cotton, leather, and traditional medicines. The disagreement between Chongqing and Wanxian regarding the normal Three Gorge reservoir water surface elevation is described in Chapter III.

As recently as July of 1981, the Yangtze rose 42 meters in three days and flooded half of the city for three days (Bonavia, Judy). Figure 14 depicts one of the older areas of Wanxian, which abuts the river directly. Note the steepness of the river banks and the natural terracing caused by the widely varying Yangtze river stages.

The Wu Gorge.

The river then plunges between the extraordinary shapes of weathered limestone in the 40-kilometer long Wuxia (Witches) Gorge. Twelve craggy mountain peaks, subjects of much legend, tower over the Yangtze. The Wu Gorge extends from the Daning River outfall in Wushan County to Guandukou in Badong County.

The Xiling Gorge.

Xiling Gorge presents by far the greatest hazard to navigation. Its reach is a nearly continuous obstacle course of shoals, whirlpools, and submerged reefs. Surface water velocity averages seven meters per
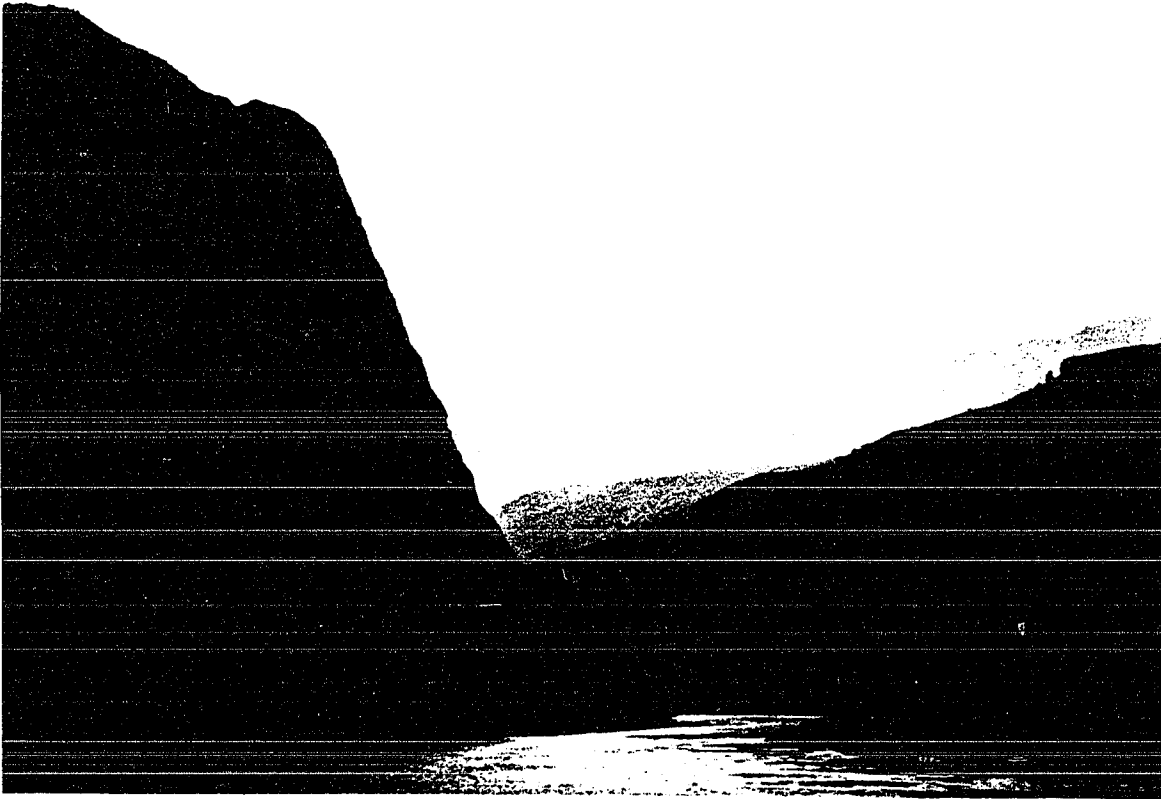
Figure 13. Entrance to the Wuxia Gorge, looking upstream (photograph
courtesy of Nicholas A. Dodge, North Pacific Division,
U.S. Army Corps of Engineers).

second (25 kilometers per hour) in some areas (Cao). It stretches 76
kilometers from the city of Xiangxi to Yichang, and is comprised of
four shorter sections named after the fantastic wind- and water-carved
limestone shapes looming over the river. These segments are referred
to as Binshubaojian (Book of War Arts and Precious Sword), Niuganmafei
(Ox-Liver and Horse-Lung), Konglin, and Mingyue (Dengying, or Shadow of
Lamp) (Liu).
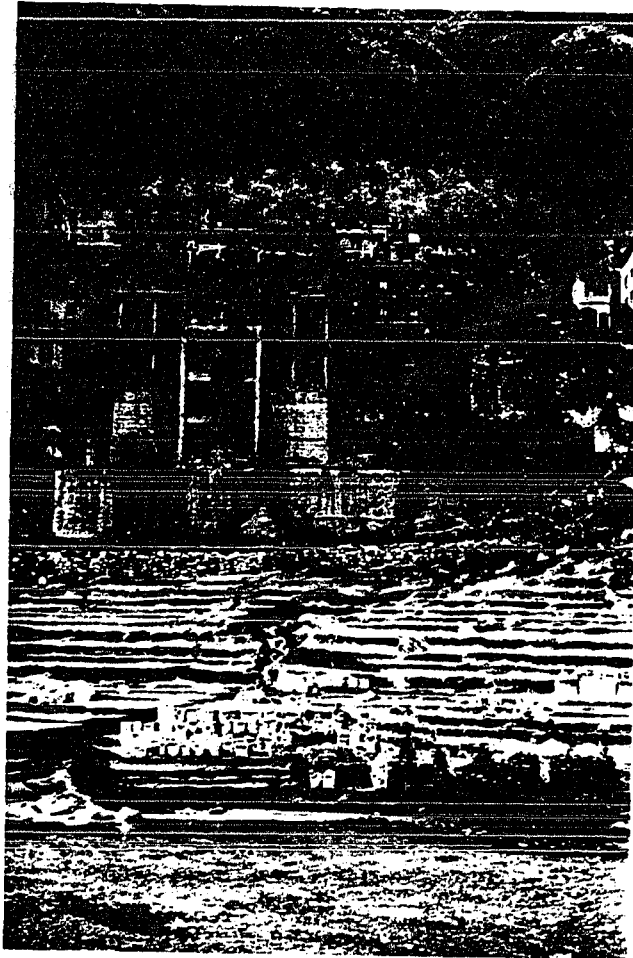
Figure 14. Section of Wanxian City. Note the terracing caused by rapidly fluctuating river levels (photograph courtesy of Nicholas A. Dodge, North Pacific Division, U.S. Army Corps of Engineers).

Navigation has always been extremely hazardous through the Three Gorges. However, over the last 35 years, the national government has eliminated more than 100 major reefs and shoals and has installed about 2,000 electric navigation lights and buoys between Yibin and Yichang at a cost of more than three billion dollars, so that shipping can go on both day and night (Liu).

The Gezhouba Dam.

Gezhouba Dam is a key project located within the boundaries of a "hydroelectric city" specifically built to house the workers that built the dam. The city is located close to Yichang and provides complete service to 130,000 people, and will serve as the base for construction teams working on the Three Gorge Dam (Jianqun).

Gezhouba is located only two miles downstream from Nanjinguan, the exit of Xiling Gorge (Cao). Its purposes include hydropower, navigation, irrigation, and limited flood control. It was built at a cost of about $3 billion and will serve as a reregulator for Three Gorge Dam. Gezhouba is a gravity structure 2,606 meters long and a maximum of 47 meters high, which houses the world's largest low-head hydroelectric plant at 2,715 megawatts. The structure consists of a left-bank powerhouse with two 170 MW turbines and five 125 MW turbines; a right powerhouse with fourteen 125 MW turbines; a 21 bay spillway; a large ship lock near each river bank; a smaller ship lock near the left bank; and four sediment sluicing channels (Jianqun).

The powerhouses will produce 13.8 million megawatt-hours of energy annually (IWP+DC, 1981b). The first generating units came on-line in 1981, and the last unit will begin service in 1988. It is expected that Gezhouba power revenues will cover the project's entire investment cost by 1989. It is entirely possible that subsequent revenues will help finance the construction of Three Gorge Dam.

The total discharge capability of the structure is equivalent to the 1,000 year peak flood flow of 110,000 cubic meters per second

(CMS). Near the end of construction in 1981, the Gezhouba project safely passed the 100-year peak flood flow of 72,000 CMS.

The three locks at Gezhouba are capable of passing 45 million tonnes of freight annually. In 1983, the project locked through 4.2 million tonnes of cargo on 57,600 vessels (ENR, 1984). Currently, the annual river cargo volume at Yichang is 50% greater than it was before construction of Gezhouba began (Jianqun). Currently, the locks are operational only during daytime hours, due to the danger of travel through the narrow Three Gorges at night. In addition, most river traffic is suspended when the unregulated Yangtze flow exceeds 45,000 CMS. These high flows are diverted through Gezhouba's four sediment-flushing sluiceways, which remove about 90% of the existing accumulated sediment. The remainder must be removed by dredges (USBR, 1984).

At the present time under good conditions, a 6,000 horsepower tugboat can push three 1,500 tonne barges of dimension 80 X 36 meters each upstream into the Three Gorges and can bring six such barges with a total load of 10,000 tonnes downstream. Currently, river freight is about 2,300,000 tonnes annually below Wuhan, but only about 65,000 tonnes annually through the Three Gorges, due to dangerous navigating conditions (USBR, 1984).

THE MIDDLE REACH OF THE YANGTZE RIVER

Introduction.

The middle reach of the Yangtze River is considered to be the 1,010 kilometer stretch from the downstream end of the Three Gorges to the mouth of Poyang Lake in Jiangxi Province. The 400 kilometer reach

between Zhicheng, Hubei Province, and the mouth of Dongting Lake, at Chenglingji, Hunan Province, is called the Jing River. This reach travels through one of the breadbaskets of China, the Jianghan and Dongting Lake Plains, together known as the Lianghu Plain (Cao).

The Yangtze loops extensively as it meanders through the Lianghu Plain, and deposits large quantities of silt, continuously raising the level of the riverbed. As this process has continued through the centuries, the people have raised the levees on either side of the river until they have reached an average height of from 10 to 16 meters.

Before Liberation in 1949, the Jianghan Plain, lying below the elevation of the perched Yangtze channel, was the worst flood disaster area in the entire Yangtze River basin. In 1950, the massive Jinjiang flood control program, which included dike repair and channel straightening on a huge scale, was launched. Several hundred two-way pumping stations were built along the Yangtze and its major tributaries in this area. By 1973, the project, operated for flood control, irrigation, navigation, and hydropower, was essentially complete.

The Jingjiang Flood Diversion Project.

The Jingjiang flood flow diversion project is located about 40 kilometers south of the city of Shashi, in southcentral Hubei Province. This immense and complicated project is a major part of the system which controls the major floods that arise from the Yangtze river and four of its major tributaries.

The project's key component, which resembles the Old River Control Structure on the lower Mississippi River, consists of a 1,054 meter

long intake structure with 54 apertures, a 335 meter long regulating
sluice with 32 apertures, and the Shashi diversion basin with a
capacity of 4.9 cubic kilometers of water (Cao). This basin,
constructed in 1954, covers 920 square kilometers and required 300,000
workers for its completion over a period of only two and one-half
months. These works are on the opposite bank from the 180-kilometer
long Jingjiang levee on the north bank of the Yangtze, which protects
the Hanjiang Plain and Wuhan.

Dongting Lake.

Dongting Lake, China's second largest at 3,000 square kilometers,
is located near the eastern end of the border between Hubei and Hunan
Provinces, south of the Jing River. This land is extremely productive
year round, and 6,100 linear kilometers of irrigation and drainage
channels, which are served by 15,000 sluices, are rich in fish
(Bonavia, Judy).

Dongting Lake serves as a repository for floodwaters from the
Xiang, Zi, Yuan, and Li rivers, which drain into it. A regulated
discharge is released into the Yangtze River downstream of the Jinjiang
flood diversion area (Liu).

Wuhan and the Han River.

Wuhan, the "Thoroughfare of Nine Provinces," is the capitol of
Hubei Province. The city has a population of about 3.7 million and is
located at the confluence of the Yangtze and Han Rivers. It is the
largest trade and industrial center in Central China, and primary
industries include those typical of large, lower Yangtze basin cities:

metals processing, machinery production, electronics, textiles, and chemicals.

Wuhan is composed of three smaller cities, Hankou on the north bank of the Yangtze, Wuchang on the south bank, and Hanyang on the banks of the Han River. The trunk Beijing-Guangzhou (Peking-Canton) railway runs north-south through the city. Most of the water conservancy institutes which study the Yangtze, including the Yangtze Valley Planning Office (YVPO), are located in Wuhan (CPH, 1982).

The Han river, one of the Yangtze's largest tributaries, rises among the Qinling Mountains in Shaanxi Province, and carries a heavy load of silt into the main Yangtze channel during summer floods. This river has flooded Wuhan eleven times during the period 1931-1949 (Liu). Dikes that contain the Han failed during the disastrous floods of 1931 and 1935, and large boats sailed in the streets of Wuhan. During the latter flood, 80,000 were killed, the entire population of the city lost their homes, and more than 400,000 hectares of farmland was inundated.

During the high-flow season extending from May to October, the Yangtze can float 10,000 tonne vessels from Shanghai to Wuhan and 8,000 tonne vessels as far upstream as Yichang. The minimum dry-season channel depth at Wuhan is five meters, which limits ocean-going vessels to 5,000 tonnes deadweight. This shallow river depth does not hinder operations at Wuhan's large port, which consists of three terminals; the Hangyan, and Hankou-1 and -2. These three terminals handle 7.6 million tonnes of cargo each year, including 2.7 million tonnes of coal, 1.1 million tonnes of steel, and 3.8 million tonnes of other bulk

cargo. During low flow periods, the Hangyan dock can handle 1000 tonne barges when dock draft is 2.6 meters (USBR, 1984).

Poyang Lake.

At a distance of 300 river kilometers east of Wuhan, the Yangtze and five other major rivers (Ganjiang, Fuhe, Xiushui, Xinjiang, and Raohe) empty into Poyang Lake, in Hukou County, Jiangxi Province. Poyang Lake is China's largest during high-flow periods, at 5,055 square kilometers (Liu).

The alluvial plain around this huge lake supports two million hectares of agricultural land. The climate in this area is mild and rainfall is abundant. This land was rendered almost uninhabitable before 1950 due to snail fever (schistosomiasis), but an intensive eradication campaign that began in the early 1950's wiped the snails out by 1958 (C3GPDC).

Below Poyang lake, the river's slope is extremely shallow, and so it meanders extensively and becomes essentially a string of shallow lakes. The river has tides as far upstream as Datong in Anhui Province.

Nanjing.

Nanjing (Southern Capital), the capitol of Jiangsu Province, has a population of more than three million, many of whom work in the city's extensive industrial sector. This area produces chemicals, machinery, steel, ships, automobiles, electronics and telecommunications equipment. The city has a busy year-round port, and the Beijing-Shanghai railway runs through it.

Further downstream, the Jiangdu water transfer project is located east of Yangzhou, and would be the first large channel to divert Yangtze River waters to parched northern China (Biswas, 1983).

THE YANGTZE RIVER ESTUARY

Physical Characteristics.

The Yangtze River and the 1,782-kilometer long Beijing-Hangzhou Grand Canal, built in the 6th and 7th centuries, meet at Zhenjiang. The Grand Canal is being upgraded for coal transportation at this time, and is currently used to irrigate the arid northern plains and supply water to the cities of Peking and Tianjin. The canal is spanned by more than twelve thousand foot and vehicular bridges.

At this point, 63 kilometers east of Nanjing, the Yangtze Delta begins, as the watercourse widens from a rock-restricted 1,200 meters at Jiangyin to 91 kilometers below the confluence with its last major tributary, the Huangpu River (Bonavia, Judy). There are more than 250 freshwater lakes in the delta region, including Taihu Lake, the third largest in China at 2,250 square kilometers. The estuary is divided by 1,083 square kilometer Chongming Island into the major North and South Channels. Chongming Island is the major source of agricultural products for Shanghai and Nanjong, whose combined population is nearly 20 million. The main navigation channel lies in the South branch.

The Yangtze delta has an area of 52,000 square kilometers, and includes most of the city of Shanghai, which lies south of it. Nantong, a major industrial and textile center with a population of 7.5 million, lies north of the delta. Almost the entire area is less than 10 meters in elevation, and rich alluvial soils produce an abundance of

products, including cotton, oils, bamboo, teas, jute, and rice. Most of China's 'three precious fish' - white fish, white prawn, and meiqi fish, are taken in the delta.

Current studies of the estuary at Shanghai's East China Design Institute are concerned primarily with (1) silt and salt intrusion into the navigation channel in the South branch, (2) stabilization of this channel, and (3) deepening of the channel at the entrance bar. Current dredging can only deepen the channel in the estuary entrance to seven meters, which is generally adequate only for ships of up to 25,000 tonnes deadweight (Corps, 1985). This is a serious problem, in light of the fact that larger world fleet vessels encounter lengthy delays because they must use lighters in deeper waters to unload.

Shanghai City.

Shanghai, the "Gateway to the Yangtze River Basin," is one of the three municipalities directly under the Chinese central government (the other two are Peking and Tianjin). It is one of the largest cities in the world, with an area of more than six thousand square kilometers and a population of more than 12 million (Bulkley; CPH, 1984). The city sprawls across the Yangtze River estuary, and due to population pressures, much new development in the city is underground. This poses a serious threat to life and property, since the city's floodwalls, raised as many as four times in the last fifty years, offer at best only 100-year flood protection (Corps, 1985).

Shanghai is the most heavily industrialized city in China, boasting more than seven thousand factories. The Port of Shanghai, on the Huangpu River, is the largest in China, handling about 100 million

tonnes of cargo each year, which consists mostly of coal from North China. The Huangpu records an average of 800 vessel passages per hour at its mouth, and congestion is severe due to inadequate facilities. The port plans to spend more than $1 billion during the next five-year plan for new and larger berths.

APPENDIX B

GENERAL OUTLINE OF PROJECT CONSEQUENCES

INTRODUCTION

All of the benefits and costs of any water resources project may
be divided into several categories in order to assist in the accounting
process. One common system of labeling and categorization is shown
below. The body of this appendix, which is presented in the same order
as the outline, explains each category in greater detail.

    I. Tangible Consequences
        a. Primary
            (1) Direct
            (2) Indirect
            (3) Land Enhancement
        b. Secondary
            (1) Stemming-From
            (2) Induced-By
        c. Employment
        d. Public
   II. Intangible Consequences
  III. Project Construction Costs
        a. Associated Costs
        b. Induced Costs

TANGIBLE CONSEQUENCES

General.

Tangible consequences differ from intangible effects in that they
may be assigned a monetary value by the use of relatively
straightforward procedures. Extramarket consequences may still
classified as tangible if they can be evaluated without using indirect
procedures. While many commercial benefit-cost analyses will account

only for tangible consequences and project construction costs, no properly-executed social analysis will neglect intangible benefits and costs.

Primary Tangible.

General. Primary tangible consequences are those that are a direct physical effect of a water resources project – not effects transmitted through subsequent market transactions (Howe, Charles). The value of these consequences are obtained from project-produced goods and services as described below.

Direct Primary Tangible. These benefits and costs accrue to those groups and persons who put the output of the project to its intended use. Direct primary benefits include the net gain in crop income from a lower-value crop which results because of the elimination of flooding, and the increase in land value when agricultural land is converted to urban or industrial land uses.

There are two general methods for estimating direct primary benefits: by the market value of output produced, or by the cost of producing the same output by some alternative means. The first method is easier to apply and more reliable if a market exists for project output or if this output can be tied to specific market commodities. For pure competition,

Gross benefit = (unit market price) X (output quantity).

The following conditions must exist if market prices are to be accurately used (Howe, Charles):

* the economy must have a high degree of competition so that prices are not arbitrary, but relate closely to actual costs,

* the economy's labor pool and productive capabilities must be at or near capacity so that the money wages that employers pay and rates of return to capital expected by management reflect <u>real</u> "opportunity costs", and

* there must be no external effects present in the form of natural monopolies, outside intervention (i.e., price regulations), and export-import restrictions (James).

If these conditions do exist, shadow prices may be estimated with an economic model.

The alternative-project method is subject to high-level tinkering in government circles. It assumes that some type of project will be built in the first place, and it will naturally always justify the 'favorite' project because the second-best alternative is always more expensive. This abuse can be prevented by selecting an alternative to the proposed project that has entirely different elements; i.e., a coal-fired and combustion turbine alternative to a large hydropower station. The only case when the alternative-project cost can be directly taken as a benefit is when another project which will have exactly the same effects will inevitably be constructed by another entity if the project under study is not built.

If project output will be large with respect to overall current regional or national output, its output will affect regional or national prices. Commodity prices or unit values may vary with project output, and a demand curve must be derived. Benefits will generally equal the aggregate value in use. If no direct market exists for a certain project output, benefits may be implied from demand curves developed through an analysis of output-related market gains and losses. This process is normally performed for flood control and irrigation benefits.

Indirect Primary Tangible. Indirect primary tangible consequences arise from the project's technological external effects. For example, a reservoir provides flood control (direct primary), but also reduces the interruptions and wages lost by workers and perhaps also the crop losses suffered by farmers when industrial or food-processing plants are closed by flooding (indirect primary). An irrigation project which prevents the loss of topsoil to duststorms, thereby preserving the productivity of the land, also provides indirect primary benefits (Howe, Charles).

Indirect primary benefits may be most efficiently evaluated by assessing each project technological external effect. The magnitude of these effects can be determined by interviewing those directly affected; workers, travelers, and farmers in a flood area, for example. Unit economic values can then be assigned by market analysis. In the absence of a better method, indirect benefit:direct benefit ratios may ba applied (for example, indirect benefits = 20 percent of direct benefits). This is a 'quick and dirty' estimating method, and should only be done for very preliminary studies, and in the absence of other data (James). Since indirect primary benefits may prove to be extremely large, it is essential that they be better quantified as project studies progress and more money is made available for staff time.

Land Enhancement Primary Tangible. These benefits are those accruing to agriculture through more productive land use brought about by the project (as opposed to direct benefits). For example, flood control projects not only protect land from flooding (direct primary),

but allow farmers to switch to more capital-intensive land uses, such as higher-value crops. These benefits are estimated as the net income from the higher-value crop <u>with</u> flood protection minus the net crop income from a lower-value crop on the same land <u>with</u> flood protection as well.

Land enhancement primary tangible benefits may be quantified if it can be proven that land use will significantly change because of a water resources project. If the analysis is done from a national accounting stance, a simple shift from one area to another will count as a zero net benefit. Urban land-enhancement benefits are equal to the rise in land value from construction that would not occur without the project minus the loss in land value in the area from which the development has shifted (Howe, Charles).

Secondary Tangible.

General.
Secondary tangible benefits are usually extremely difficult to quantify, and therefore any calculations will be arbitrary in nature. Any private or public investment has numerous secondary benefits, and since their evaluation is based on arbitrary assumptions, they are of little value in helping decide which of several alternative plans is the most 'desirable' (Kuiper). One indirect method is to estimate secondary benefits as a percentage of direct benefits. In the United States, this percentage, according to project purpose, can range up to twice the value of direct benefits.

Secondary benefits can be large from a local standpoint, but may be quite small in proportion from a national accounting stance. In times of full employment, they can become essentially zero from a

national standpoint (Eckstein). From a national accounting stance, secondary benefits equal the economic value of the secondary consequences of the water resources project minus the displaced investment. Assuming that water resources projects have more linkage investments than other projects, a small figure (say 10 percent of direct benefits) may be assumed, but no backup data can exist for such an arbitrary assumption (James).

"Stemming-From" Secondary Benefits. If present, these benefits arise from forward production linkages that increase the income of those who process various direct and indirect project outputs. For example, vegetables will pass through several processes in the hands of middlemen before being sold, and will increase the processsor's income over what it was before the project was built. Total stemming-from benefits are equal to the profits reaped from processing the additional increment of plant output that exists solely because the project was built.

"Induced-By" Secondary Benefits. If present, these benefits arise from backward production linkages that increase the net income of those who provide goods and services to the project area. For example, additional vegetables produced by land irrigated by a project will require the purchase of farm machinery, fertilizer, and other equipment, and will bring a profit to those who sell these goods. Total induced-by benefits are equal to the profits gained by those servicing the project area less the loss in income to those who would provide goods and services to the project area in the absence of the project and any displaced investments. Total induced-by benefits are

sometimes taken as a certain percentage of direct benefits in some
countries (McKean).

Employment Benefits and Costs.

Employment benefits consist of the economic value of the increased
employment that results from the planning, construction, and operation
and maintenance of all phases of the water resources project. This
benefit can be estimated as the total wages paid to previously
unemployed workers plus the increase in wages paid to previously
underemployed workers. It must be proven that there is a dearth of
alternative local employment and that the unemployed and underemployed
are essentially immobile. It must be remembered that high employment
will exist during project construction, and will fall off drastically
after project completion.

Indirect employment benefits include the following;

* increased employment due to production and processing of
    project output,

* increases in standard of living to those living elsewhere on a
    marginal income who are attracted to the area to work on the
    project and its outputs (especially agriculture); and

* increased investment opportunity on farms and in local
    businesses in the project area (James).

The social cost of labor is defined as the alternative
productivity of the required labor force in the absence of the
project. With extensive unemployment, this value may approach zero.
If a force of substantially unemployed people will be used to construct
the project, the social cost of labor is derived by multiplying each
cost class (wages and capital cost) by one minus the probability that

the inputs will be drawn from the ranks of the unemployed (Howe, Charles).

Public Benefits.

Public benefits accrue to the 'local' area through the fulfillment of non-economic goals, and are usually quite difficult to evaluate in monetary terms. They must necessarily be subjected to a value judgement. These objectives include economic stabilization, income redistribution, regional development, and environmental quality improvement.

INTANGIBLE BENEFITS

Intangible (extramarket) consequences are not measureable in units of dollars and present the most intractible of all evaluation problems. Intangible benefits include the greater security against loss of life and subsequent peace of mind brought about by knowing that farmland and other assets will not be flooded on a regular basis. Other benefits are the value associated with the preservation of unique scenic, scientific, or historic artifacts or structures, preservation of the environment, and the improvement of health-promoting conditions.

There are many intangible costs associated with the relocation of people from their places of residence. Monetary resettlement costs may be estimated, but the sacrifice of the people cannot be estimated in monetary terms; i.e., stress brought on by the disruption of routine, finding new jobs, loss of longstanding social relationships, the traditional and religious value of long-held land, and the conflicts between the newly resettled and their neighbors (Howe, Charles). Further examples of relocations impacts are described in Chapter V.

PROJECT CONSTRUCTION AND OPERATION COSTS

General.

These costs are those direct costs associated with constructing and operating the project, and are listed below (Clowes, 1987a). These costs are discussed in Chapter IV.

* engineering, design, supervision and administration (ED&SA);
  * preparing plans and specifications for the entire project
  * inspection of construction work
  * special review and investigations (e.g., hydraulic studies)
  * engineering technical review

* construction of joint-use facilities;
  * dam embankment   * spillway
  * land and rights-of-way   * outlet works
  * land clearing   * relocations

* construction of purpose-specific facilities;
  * navigation locks, harbors, and signals
  * hydropower facilities (powerhouse and enclosed equipment)
  * irrigation (pumps, canals)
  * recreation (boating, hiking, camping, picnicking facilities)

* annualized operation, maintenance, and replacement (Clowes, 1987b);
  * operation of navigation and hydropower features
  * preventative maintenance on equipment
  * power purchases for pumping (irrigation and pumped-storage hydropower)
  * channel clearing
  * embankment erosion and riprap repair
  * recreation area cleaning and maintenance
  * replacements of major worn mechanical components (this cost is generally assumed to be a fixed percentage of the project construction cost - for example, 0.1 percent for concrete spillways).

Associated Costs.

Associated costs are incurred by private investment so that they may produce or use water resource project outputs. For example, farmers, in order to take advantage of irrigation water not previously available, may switch from dryland to irrigated farming. This would

require them to prepare their land, purchase new equipment (to include sprinklers, perhaps), and convert to the new cropping pattern. If a large population shift occurs into the project area, the costs of the new infrastructure (schools, roads, hospitals, etc.) must be prorated to those people who have moved specifically due to the project or its outputs.

Induced Costs.

These are costs associated with changes brought on by project construction, to include;

* costs of increased transportation distances around the reservoir,

* costs of drainage systems to remove irrigation water, and

* costs of local facilities to cope with influx of visitors to the recreation site on the reservoir.

UNACCOUNTED INPUTS AND UNINTENDED OUTPUTS

While assessing the above categories of benefits and costs, it is particularly important to avoid double-counting unaccounted inputs and unintended outputs.

Unaccounted inputs are those resources and inputs that are consumed free of charge by the project, but which have value to society, such as scenery, water, air and peace. These inputs may take the form of an increment of depreciation on components of the existing infrastructure, including roads, communications, and industrial facilities. They may also be the use of housing, schools, and other facilities by the workers and families of the construction agency. The costs of these facilities must be prorated by actual use of the agency's people.

Unintended outputs are the generally negative byproducts of a project that have not been estimated, such as the value of better roads and of air and noise pollution. The project usually cannot control these outputs or dispose of them. There is no perceivable demand for them, but they must be accounted for in a benefit-cost analysis.

The cost-benefit analysis must avoid double-counting the duality between unintended outputs and unaccounted inputs. One example would be the production of carbon dioxide as an unintended output, which reduces the quality of the air, which is an unaccounted input (Qayum, 1983).

APPENDIX C

THE SCRB COST ALLOCATION

THE PURPOSE OF A COST ALLOCATION

Outline.

The separable-costs remaining benefits (SCRB) method of cost
allocation for multiple-purpose water resource projects was originally
proposed by the United States Federal Inter-Agency Subcommittee on
Benefits and Costs in its 1950 report on "Proposed Practices for
Economic Analysis of River Basin Projects."

A cost allocation encourages the most economical use of project
inputs and outputs. , Because a cost allocation shows how much of the
project's total costs will be dedicated to each purpose, it is a
financial, not an economic, analysis.

The general purpose of an SCRB cost allocation is to determine
whether or not all project purposes can be supported by the benefits
that accrue to those purposes. Each component of a multiple-purpose
dam and reservoir is either specific to one project purpose (for
example, hydropower turbines, navigation locks, and fish ladders), or
is a "joint-use" component that serves one or more purposes (such as
outlet works, which may serve both low-flow augmentation and navigation
purposes). If the component cannot be identified as serving any
specific purpose, such as embankment and reservoir clearing costs, or

general O&M costs, they are called "joint costs" or "common costs."

Separable Costs.

If a project serves more than one project purpose, the cost assigned to each purpose will be the cost of the project with the purpose minus the cost of the project without the purpose. This is called the separable cost of the project purpose. For example, if a dam is to serve the purposes of flood control, irrigation, navigation and hydropower, the separable cost of navigation is the cost of the four-purpose project minus the cost of the identical project built only for flood control, irrigation, and hydropower.

General Guidelines.

By its very nature, cost allocations are indeterminate and controversial in nature. Each party will want the burden of payment to be shifted to others. Many assumptions will have to be made in a major cost allocation. Despite its drawbacks, the cost allocation remains one of the most equitable and impartial method for the resolution of conflicting interests. There is no strictly standard method for allocating costs, but, as a minimum, the following rules must be followed;

* the cost allocation should be performed in the simplest possible manner. Conflicting interests are more likely to accept computations that they can understand.

* as described above, the allocation of cost to any project purpose must be more than its separable cost, but less than the benefits it provides.

* the sum of all costs allocated to the project purposes must equal the total project cost.

* joint-use facilities must be operated in accordance with the final cost allocation. The allocation is rendered insupportable and artificial in its conclusions if a disproportionate amount of a project's cost is allocated to a purpose having a low priority in project operation, such as recreation.

* the cost allocated to each project purpose will determine the price charged to users of that purpose. If the allocation to each purpose results in a charge to the individual user that approximately equals the marginal cost of serving him, he is encouraged to use project outputs in an economically efficient manner.

THE COST ALLOCATION PROCEDURE

A cost allocation is performed in three general steps;

(1) the allocation assigns to each project purpose any costs which are necessary in order to include that purpose in the project (referred to as 'separable' costs). This amount is the minimum cost allocated to each purpose. For example, if a project can be built to serve five purposes for $235 million, but could be built to serve four of those purposes for $185 million, the additional expenditure of $50 million is made necessary solely by the fifth purpose and is definitely assignable to that purpose - its "separable cost." This is the minimum amount of cost to be assigned to this purpose.

(2) the "joint costs" of the project are determined by subtracting the sum of the separable costs from the total costs of the proposed multiple-purpose project. These joint facilities are necessary for the operation of each project purpose, and their costs must be allocated to all such purposes. These joint costs are distributed among the project purposes in the same ratios that the remaining benefits bear to the sum of all remaining benefits.

(3) between these limits, project costs are allocated so that each purpose shares equitably in any advantages of the joint project that would be absent if a single-purpose project only were built. The total allocation of costs to each project purpose is computed by adding the separable costs and the share of joint costs for each purpose.

The allocation assigns to each project purpose no more costs than the benefits that will result from such costs nor more than the cost of the most economical alternative way in which such outputs could be

realized. This would be the maximum amount allocated to each purpose.

The cost allocation makes use of previous studies which have determined the least costly manner of achieving each single purpose of the project separately. These are known as the costs on the alternative single-purpose project. For example, in a case where flood control benefits of $25 million a year could accrue from the project's construction, it may be possible to protect the same area and get the same benefits by constructing levees, floodproofing, or even construction a single-purpose flood control dam at the identical site. If the estimated costs of a combination of levees and floodproofing were only $18 million, it would be uneconomical to assign to flood control more than $18 million of the costs of a multiple-purpose project, even though it would be economically sound to incur up to $25 million in costs for flood control if a less costly means of realizing the benefits was not available. Therefore, for each purpose of a multiple-purpose project, the amount of benefits, or the cost of the most economical alternative method of achieving the same benefits, whichever is less, is the limiting figure on the total amount of cost that should be allocated to the purpose.

Example Cost Allocation.

Table XLV shows an example calculation of the specific and joint-use costs of a proposed three-purpose water resource project. Tables XLVI and XLVII, respectively, summarize the costs of the alternative purpose-omitted (dual purpose) and single-purpose projects that could be constructed in the place of the proposed scheme. Table XLVIII shows the results of a computer-generated SCRB cost allocation.

TABLE XLV

SUMMARY OF CONSTRUCTION AND ANNUAL COSTS,
APPROVED FORT SCOTT PROJECT CONFIGURATION

(all costs in $thousands)

Project Feature	Specific Recreation Costs	Joint-Use Costs	Total Project Costs
Relocations of Housing and Value of Inundated Land	559	20,441	21,000
Relocations of Persons	0	15,956	15,956
Land Clearing	0	1,848	1,848
Embankment Construction	0	27,575	27,575
Relocations of Roads, Railroads, and Bridges	0	984	984
Recreation Facilities	4,079	0	4,079
Buildings, Grounds, Utilities	0	557	557
Permanent Operating Equipment	0	381	381
Cultural Resource Preservation	19	701	720
Subtotal	4,657	68,443	73,100
Interest During Construction	883	12,975	13,858
Project Investment Cost	5,540	81,418	86,958
Annual Financial Costs			
Interest and Amortization	388	5,706	6,094
Operation and Maintenance	390	480	870
Major Replacements	7	40	47
Total Annual Project Costs	785	6,226	7,011

This cost allocation assumes even expenditures over the project construction time of five years. Interest during construction and interest and amortization are calculated at seven percent interest.

TABLE XLVI

SUMMARY OF CONSTRUCTION AND ANNUAL COSTS, PURPOSE OMITTED PROJECTS

(all costs in $thousands)

Project Feature	Flood Control Omitted	Recreation Omitted	Water Supply Omitted
Relocations of Housing and Value of Inundated Land	15,150	20,441	20,245
Relocations of Persons	3,531	15,956	14,387
Land Clearing	1,910	1,848	1,592
Embankment Construction	22,683	27,575	26,872
Relocations of Roads, Railroads, and Bridges	984	984	984
Recreation Facilities	4,079	0	4,079
Buildings, Grounds, Utilities	557	557	557
Permanent Operating Equipment	381	381	381
Cultural Resource Preservation	490	670	690
Subtotal	49,765	68,412	69,787
Interest During Construction	9,434	12,969	13,230
Project Investment Cost	59,199	81,381	83,017
Annual Financial Costs			
Interest and Amortization	4,149	5,703	5,818
Operation and Maintenance	850	480	853
Major Replacements	45	40	45
Total Annual Project Costs	5,044	6,223	6,716

This cost allocation assumes even expenditures over the project construction time of five years. Interest during construction and interest and amortization are calculated at seven percent interest.

TABLE XLVII

SUMMARY OF CONSTRUCTION AND ANNUAL COSTS, SINGLE-PURPOSE PROJECTS

(all costs in $thousands)

Project Feature	Flood Control	Recreation	Water Supply
Relocations of Housing and Value of Inundated Land	13,850	14,325	12,785
Relocations of Persons	11,248	2,223	1,177
Land Clearing	2,229	1,592	1,370
Embankment Construction	25,903	21,959	18,272
Relocations of Roads, Railroads, and Bridges	984	984	984
Recreation Facilities	0	4,079	0
Buildings, Grounds, Utilities	557	557	500
Permanent Operating Equipment	381	381	381
Cultural Resource Preservation	550	460	350
Subtotal	55,702	46,560	35,819
Interest During Construction	10,560	8,827	6,790
Project Investment Cost	66,262	55,387	42,609
Annual Financial Costs			
Interest and Amortization	4,644	3,882	2,986
Operation and Maintenance	370	760	380
Major Replacements	35	40	40
Total Annual Project Costs	5,049	4,682	3,406

This cost allocation assumes even expenditures over the project construction time of five years. Interest during construction and interest and amortization are calculated at seven percent interest.

TABLE XLVIII

FORT SCOTT PROJECT COST ALLOCATION

	Flood Control	Recreation	Water Supply	Total
Allocation of Annual Costs				
1. Benefits	3,369,300	1,750,000	4,114,000	6,233,300
2. Alternate costs	5,049,000	4,682,000	3,406,000	
3. Limited benefits	3,369,300	1,750,000	3,406,000	5,525,300
4. Initial separable cost	1,967,000	788,000	295,000	3,050,000
5. Remaining benefits	1,402,300	962,000	3,111,000	5,475,300
6. Percent	25.61	17.57	56.82	100.00
7. Allocated joint cost	1,014,412	695,948	2,250,640	3,961,000
8. Total allocation	2,981,412	1,483,948	2,545,640	7,011,000
Allocation of Operation and Maintenance				
9. Initial separable cost	20,000	390,000	17,000	427,000
10. Allocated joint cost	113,452	77,835	251,713	443,000
11. Total allocation	133,452	467,835	268,713	870,000
12. Specific cost		390,000		390,000
13. Joint-use cost	133,452	77,835	268,713	480,000
14. Joint-use ratio	27.80	16.22	55.98	100.00
Allocation of Major Replacements				
15. Separable cost	2,000	7,000	2,000	11,000
16. Allocated joint cost	10,872	2,736	22,392	36,000
17. Total allocation	12,872	9,736	24,392	47,000
Allocation of Investment				
18. Annual investment cost	2,835,088	1,006,377	2,252,535	6,094,000
19. Percent	46.52	16.51	36.97	100.00
20. Allocated investment	40,452,900	14,356,800	32,148,300	86,958,000
Allocation of First Cost				
21. Specific investment		5,540,000		5,540,000
22. Joint use investment	40,452,900	8,816,800	32,148,300	81,418,000
23. Joint-use IDC	6,446,700	1,405,100	5,123,200	12,975,000
24. First joint-use cost	34,006,200	7,411,700	27,025,100	68,443,000
25. Percent of construction cost in joint-use	49.69	10.83	39.48	100.00
26. First specific cost		4,657,000		4,657,000
27. Total first cost	34,006,200	12,068,700	27,025,100	73,100,000
28. Percent	46.52	16.51	36.97	100.00

An explanation of these line items is provided in TABLE XLIX.

TABLE XLIX

EXPLANATION OF LINE ITEMS, TABLE XLVIII

1. Results of other preliminary studies which determined the various benefits attributable to the approved project configuration (not described here).
2. Annual financial costs of single-purpose projects (Table XLVII).
3. Greater of line 1 or line 2.
4. Annual cost of the approved project configuration minus the annual cost of the appropriate purpose-omitted project.
5. Line 3 minus line 4.
6. Percent of line 5.
7. Total annual cost of the approved multiple-purpose project minus the total cost of line 4, allocated by the percentages shown in line 6.
8. Total of line 4 and line 7.
9. Annual O&M cost of the approved project configuration minus the annual O&M cost of the appropriate purpose-omitted project.
10. Total annual O&M cost if the approved multiple-purpose project minus the total of line 9, distributed by the percentages shown in line 6.
11. Total of line 9 and line 10.
12. Costs due specifically to one project purpose.
13. Line 11 minus line 12.
14. Percent of line 13.
15. Annual replacements cost of the approved project configuration minus the annual replacements cost of the appropriate purpose-omitted project.
17. Line 15 plus line 16.
18. Line 8 minus line 11 minus line 17.
19. Percent of line 18.
20. Multiple-purpose project cost allocated by percentages given in line 19.
21. Specific project purpose investment costs (from Table XLV).
22. Line 20 minus line 21.
23. Joint-use interest during construction (from Table XLV) distributed in same ratio as values in line 22.
24. Line 22 minus line 23.
25. Percent of line 24.
26. Specific project purpose construction costs (from Table XLV).
27. Line 24 plus line 26.
28. Percent of line 27.

APPENDIX D

CONVERSION FACTORS

General Conversion Factors (alphabetical listing).

One:	Equals
acre	4,047 square meters
	2.20 mou
	0.405 hectares
acre-foot	43,560 cubic feet
	1,233.5 cubic meters
	0.504 second-foot day
barrel	159.0 liters
	42.0 US gallons
	34.97 imperial gallons
British thermal unit (BTU)	1,055.4 joules
	778.16 foot-pounds
	0.293 watt-hour
	0.252 kilocalories
Cubic foot per second (CFS)	723.97 acre-feet per year
	7.481 gallons per second
	0.646 million gallons per day
	0.0283 cubic meters per second
degrees Centigrade	$^{\circ}C = (^{\circ}F-32) \times 5/9$
degrees Farenheit	$^{\circ}F = (^{\circ}C+32) \times 9/5$
foot	0.305 meters
foot^2	0.093 square meters
foot^3	0.0283 cubic meters
	7.48 U.S. gallons
	62.4 pounds (fresh water)

General Conversion Factors (continued)

One:	Equals
foot-pound per second	1.356 watts 0.00182 horsepower
gallon (imperial)	4.55 liters 1.201 US gallons 0.0286 barrels
gallon (US)	8.34 pounds (fresh water) 3.79 liters 0.833 imperial gallons 0.1337 cubic feet 0.0238 barrels
gigawatt-hour (gWh)	1,000 megawatt-hours
hectare	10,000 square meters 17.83 mou 2.471 acres
horsepower	745.7 watts 550 foot-pounds per second 75 kilogram-meters per second 42.408 BTU/minute 10.68 kcal/minute 1.014 metric horsepower
joule[1]	1 watt-second 10 million ergs 0.738 foot-pounds 0.000948 BTU
kilocalorie (kcal)	4,183 joules 3.968 BTU
kilometer	0.621 miles
kilometer [3]	1 billion cubic meters 810,606 acre-feet

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[1] The basic units of energy and power are, respectively, the joule and the watt;

Watts = (volts) X (amperes) X (cosine angle of lag or lead)

General Conversion Factors (continued)

One:	Equals
kilowatt	1,000 watts 101.97 kilogram-meters per second 1.341 horsepower
kilowatt-hour (kWh)	3.6 million joules 2,656,800 foot-pounds 3,414 British thermal units 860.5 kilocalories
kilowatt-hour electrical {kWh(e)}	0.30 kWh thermal {kWh(t)} 0.1 joules
liter	0.264 US gallons 0.220 imperial gallons 0.00629 barrels
megawatt-hour (MWh)	1,000 kilowatt-hours
meter	39.37 inches
meter^2	10.76 square feet 1.196 square yards
meter^3	1,000 liters 35.31 cubic feet 1.308 cubic yards
million meter^2	810.6 acre-feet
Million gallons per day (MGD)	1,120.15 acre-feet per year 694.44 gallons per minute 3.069 acre-feet per day 1.547 cubic feet per second
mile	1.609 kilometers
mou	733.5 square yards 560.8 square meters 0.455 acres 0.056 hectares
pound	0.454 kilograms
terawatt-hour (TWh)	1,000 gigawatt-hours

General Conversion Factors (continued)

One:	Equals
ton	907.2 kilograms
	0.907 tonnes
tonne	1.102 tons
	1,000 kilograms
watt-hour	36 billion ergs
	3,600 joules
	3.412 BTU
yard^2	0.836 square meters

Fuel Energy Content Equivalents - Worldwide Standard (EPRI).

1 tonne of oil = 43.0 million BTU (MBTU)
$\quad\quad\quad\quad\quad$ = 44.8 billion joules
$\quad\quad\quad\quad\quad$ = 1.67 tonnes of coal
$\quad\quad\quad\quad\quad$ = 3.04 tonnes of lignite
$\quad\quad\quad\quad\quad$ = 5.67 tonnes of peat
$\quad\quad\quad\quad\quad$ = 1,170 cubic meters of natural gas

1 tonne of coal = 25.8 million BTU
$\quad\quad\quad\quad\quad$ = 26.8 billion joules
$\quad\quad\quad\quad\quad$ = 1.82 tonnes of lignite
$\quad\quad\quad\quad\quad$ = 3.40 tonnes of peat
$\quad\quad\quad\quad\quad$ = 700 cubic meters of natural gas

1 tonne of lignite = 14.1 million BTU
$\quad\quad\quad\quad\quad$ = 14.7 billion joules
$\quad\quad\quad\quad\quad$ = 0.55 tonnes of coal
$\quad\quad\quad\quad\quad$ = 1.87 tonnes of peat
$\quad\quad\quad\quad\quad$ = 385 cubic meters of natural gas

1,000 cubic meters of natural gas = 35.31 million BTU
$\quad\quad\quad\quad\quad$ = 37.1 billion joules
$\quad\quad\quad\quad\quad$ = 0.82 tonnes of oil
$\quad\quad\quad\quad\quad$ = 1.37 tonnes of coal
$\quad\quad\quad\quad\quad$ = 4.66 tonnes of peat

Fuel Energy Content Equivalents - Chinese Standard.

1 tonne of standard coal = 1.874 megawatt-hours (MWREP, 1983b).

1 tonne of standard oil = 3.644 megawatt-hours (MWREP, 1983b).

Fuel Energy Content Equivalents - Chinese Standard (continued).

1 metric ton of raw coal = 0.71 tons of standard coal equivalent.

1 metric ton of crude oil = 1.43 tons of standard coal equivalent.

1,000 cubic meters of natural gas = 1.33 tons of standard coal equivalent (Smil, 1978; JETRO).

1 cubic meter of dried wood (20 percent moisture content) = 725 kilograms = 2.68 million kcal = 3,120 kWh (Smil, 1978).

1,000 kWh hydro = 0.4222 tons standard coal equivalent (JETRO).

U.S. - China Currency Conversion Factors.[2]

Year	1 Dollar Equals
1974	1.92 Yuan[3]
1975	1.85 Yuan
1976	1.73 Yuan
1977	1.66 Yuan
1978	1.60 Yuan
1979	1.55 Yuan
1980	1.50 Yuan
1981	1.71 Yuan
1982	1.89 Yuan
1983	1.98 Yuan
1984	2.50 Yuan
1985	3.20 Yuan
1986	3.70 Yuan

Chinese Measures and Metric Equivalents.

One:	Equals
Cattie (Jin, Ging)	0.6 kilograms
Chih	0.308 meters
Chin	0.501 kilograms
Li	500 meters
Mou (10 Fen)	560.8 square meters
Picul (100 catties)	60 kilograms
Tan (100 Chin)	50 kilograms

[2] There is no general pattern in the worldwide value of the yuan, except perhaps a "mild tendency to follow the movements of the U.S. dollar and the strongest European currencies."

[3] One Yuan RenMinBi (RMB) = 100 Fen
   References: MWREP, 1983b; Smil, 1978; Nai-Reuenn; Nickum; Howe.