

# ECONOMIC AND TECHNICAL CONSIDERATIONS OF REGIONAL WATER SUPPLY

A REPORT SUBMITTED TO:  
U.S. ARMY ENGINEER INSTITUTE FOR WATER RESOURCES  
KINGMAN BUILDING  
FORT BELVOIR, VIRGINIA 22060

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

JULY 1977

CONTACT REPORT 77-7

ECONOMIC AND TECHNICAL CONSIDERATIONS  
OF REGIONAL WATER SUPPLY

A Report Submitted to:

U.S. Army Engineer Institute for Water Resources  
Kingman Building  
Fort Belvoir, Virginia 22060

Prepared by:

Gert Aron  
Stephen P. Coelen

Institute for Research on Land & Water Resources  
The Pennsylvania State University  
University Park, Pennsylvania 16902

In Cooperation with:

The Departments of Civil Engineering and Economics

With the Assistance of:

William J. Carroll  
Jerry S. Faber  
Jerrold W. Gotzmer  
Elizabeth L. White

Under Contract Number DACW31-75-C-0018

JULY 1977

IWR Contract Report 77-7

Copies may be purchased from:

National Technical Information Service  
U.S. Department of Commerce  
Springfield, Virginia 22151

This report is not to be construed as necessarily representing the views of the Federal Government nor of the U.S. Army Corps of Engineers.

## UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER IWR Contract Report 77-7	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Economic and Technical Considerations of Regional Water Supply		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Gert Aron and Stephen P. Coelen		8. CONTRACT OR GRANT NUMBER(s) DACW31-75-C-0018
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute for Research on Land & Water Resources The Pennsylvania State University University Park, Pennsylvania 16902		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS USA Engr Institute for Water Resources Kingman Building Fort Belvoir, Virginia 22060		12. REPORT DATE July 1977
		13. NUMBER OF PAGES 198
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) Approved for public release; distribution unlimited		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Water supply, regional water supply, reservoir enlargement, interbasin water transfer, land values modelling, high flow skimming		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The report seeks to evaluate the belief that regionalization of water supply holds the key to the water supply problems in the United States. To do this, the report examines the theory and practices of regionalized small water supply systems. It then investigates the case for regionalization on account of the fear for water supply shortages. This is followed by a critical look at interbasin water transfer and its problems. The report introduces an econometric model as a tool for evaluating the land value changes from regionalization of water supply. The report finds that in		

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

addition to political and institutional constraints, most regionalization plans failed because the problems of efficiency and equity were not resolved.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

TABLE OF CONTENTS

<u>CHAPTER</u>	<u>PAGE</u>
1 INTRODUCTION . . . . .	1
2 BASIS FOR THE STUDY OF REGIONALIZATION . . . . .	3
2.1 Experience With Regionalization Planning . . . . .	3
2.2 Efficiency and Equity; Integration and Extention . . . . .	10
2.3 What Lies Ahead. . . . .	11
3 REGIONALIZATION OF SMALL WATER SUPPLY SYSTEMS. . . . .	13
3.1 Principle of Economies of Scale. . . . .	14
3.1.1 Average and Marginal Cost Pricing. . . . .	18
3.2 Economies of Scale . . . . .	18
3.3 Micro-Scale Case Study . . . . .	25
3.3.1 Description of Centre Region . . . . .	25
3.3.2 Communities Selected as Regionalization Candidates . . . . .	25
3.3.3 Comparison of Local vs. Regionalized Water Supply Systems. . . . .	25
3.3.4 Public Reactions to Regionalization Proposals in Small Systems. . . . .	29
3.4 Systems Requiring Reservoir Capacities to Firm Up Their Water Supply . . . . .	30
3.4.1 Generalized Reservoir Storage Requirement. . . . .	30
3.4.2 Complete Integration of Two Supply Systems . . . . .	31
3.4.3 Supplemental Regionalization . . . . .	35
3.4.4 Analytically Optimized Regionalization . . . . .	36
3.4.5 Reservoir Cost Savings vs. Water Conveyance Costs. . . . .	42
3.4.6 The Role of Sunk Costs and Regionalization . . . . .	43
3.4.7 Conclusions in Regard to Reservoir Integration . . . . .	47
4 THE THREAT OF WATER SHORTAGES AS INCENTIVE FOR REGIONALIZA- TION OR RESERVOIR ENLARGEMENT. . . . .	49
4.1 Water Shortage Loss Functions. . . . .	49
4.2 Transformation of the Shortage Loss Function . . . . .	53
4.3 Firm Yield Analysis. . . . .	54
4.4 Shortage Index as a Function of R/Q and C/Q. . . . .	56
4.5 Tradeoff between Reservoir Costs and Shortage Losses . . . . .	59
4.6 Comparison of Shortage Costs Obtained from Hufschmidt- Fiering and Russell Curves . . . . .	64
4.7 Inclusion of Shortage Cost in a Two-Source Regional Supply System . . . . .	65
4.8 An Economic Interpretation of Shortage Losses. . . . .	70
4.9 Conclusions. . . . .	75
5 INTERBASIN WATER TRANSFER. . . . .	76
5.1 The Pro's and Con's of Interbasin Water Transfer . . . . .	76
5.1.1 Suggested Compromises to Make Interbasin Water Transfer More Acceptable . . . . .	79

## TABLE OF CONTENTS

<u>CHAPTER</u>	<u>PAGE</u>
5.2 Choice of a Macro-Scale Case Study Area. . . . .	80
5.2.1 Population Growth and Density of Indicators of Regional Water Needs . . . . .	83
5.2.2 Physical Description of the Interbasin Transfer Site . . . . .	83
5.2.3 Temporal Drought Patterns. . . . .	87
5.2.4 Comparative Drought Severity . . . . .	88
5.2.5 Storage Requirements for Given Firm Yields . . . . .	88
5.3 Alternative Plans for Water Transfer from the Susquehanna to the Delaware Basin. . . . .	92
5.3.1 Existing Delaware Reservoirs and Aqueducts . . . . .	92
5.3.2 Cost Functions Used. . . . .	96
5.3.3 Flood Skimming Scheme. . . . .	97
5.3.4 All-Year Transfer by Pipeline. . . . .	98
5.3.5 All-Year Transfer by Tunnel. . . . .	108
5.3.6 Non-Prime Time Operation . . . . .	108
5.3.7 Cost Comparison Between 9 Alternative Water Transfer Schemes. . . . .	109
5.3.8 Marginal Costs of Flood Control Provision in Addition to Low Flow Augmentation. . . . .	111
5.3.9 Monetary Compensation for Water Transfer . . . . .	113
5.4 Generalization of High Flow-Skimming Processes . . . . .	113
5.5 Conclusions. . . . .	118
 6 REGIONALIZATION, LAND VALUES AND DISTRIBUTION. . . . .	 119
6.1 Theoretical Background for Measuring Distribution . . . . .	119
6.2 The Housing Market . . . . .	121
6.3 Statistical Modelling . . . . .	131
6.3.1 Cross-Sectional Modelling. . . . .	134
6.3.2 Time Series Modelling. . . . .	138
6.4 The Distinction Between Time Series and Cross-Sectional Analysis . . . . .	144
6.4.1 Differences Between the Cross-Sectional and a Time Series Measure. . . . .	144
6.4.2 Differences Between the Pure Time Series Measure and a BMN Measure . . . . .	151
6.5 Other Considerations . . . . .	153
6.5.1 The Problem of Anticipation and Adjustment . . . . .	153
6.5.2 Property Taxes . . . . .	155
6.5.3 Externalities. . . . .	156
6.6 Selection of the Case Study. . . . .	157
6.6.1 Selecting the Time Periods for Analysis. . . . .	160
6.7 Results. . . . .	162
6.7.1 Cross-Sectional Results. . . . .	162
6.7.2 Time Series Results. . . . .	166

TABLE OF CONTENTS

<u>CHAPTER</u>	<u>PAGE</u>
6.8 Interpretation of the Results . . . . .	173
. 7 SUMMARY . . . . .	178
APPENDIX A . . . . .	183
APPENDIX B . . . . .	188
BIBLIOGRAPHY . . . . .	193

## LIST OF FIGURES

<u>Number</u>		<u>Page</u>
3.1	Typical Cost Curves. . . . .	15
3.2	Cost Curve for Utility with Economies of Scale . . . . .	16
3.3	Cost Curves for Elements of a Water Supply System, 0 to 20 Million Gallons per Day. . . . .	20
3.4	Construction Cost Curve for Impounding Reservoir, 0 to 20 Billion Gallons. . . . .	21
3.5	Location Map of Centre Region and its Townships. . . . .	23
3.6	Location Map of Potential Centre Region Water Consumption Centers. . . . .	24
3.7	Storage-Yield Relationships for Impounding Reservoirs. . . . .	32
3.8	Reservoir Cost Savings under Complete Regionalization. . . . .	38
3.9	Marginal Savings under Supplemental Regionalization. . . . .	39
3.10	Maximum Economically Feasible Pipeline Lengths, under Complete Regionalization . . . . .	44
3.11	Maximum Economically Feasible Pipeline Lengths, under Supplemental Regionalization . . . . .	44
4.1	Water Shortage Loss Function (after Russell) . . . . .	51
4.2	Water Supply Loss Function for Lehigh, Pa. and Corres- ponding Monthly Shortage Index (after Hufschmidt-Fiering). . . . .	52
4.3	Relationship of Firm Yield to Reservoir Storage Capacity . . . . .	57
4.4	Shortage Index as Function of R/Q and C/Q. . . . .	58
4.5	Reservoir Construction Cost Curves . . . . .	61
4.6	Tradeoff Between Reservoir Costs and Shortage Losses (Q = 1 bg/yr). . . . .	62
4.7	Tradeoff Between Reservoir Costs and Shortage Losses (Q = 4 bg/yr). . . . .	63
4.8	Comparison of Shortage Loss Functions. . . . .	66
4.9	Effect of Shortage, Pipeline Length and Gradient on Regional Water System Costs ( $C_1 = 1$ bg) . . . . .	68

LIST OF FIGURES (Continued)

<u>Number</u>		<u>Page</u>
4.10	Effect of Shortage, Pipeline and Gradient on Regional Water System Costs ( $C_1 = 1.5$ bg) . . . . .	69
5.1	New York Study Area. . . . .	81
5.2	New York Regional Supply System. . . . .	82
5.3	Regional Water Needs vs. Population Density. . . . .	84
5.4	Temporal Drought Patterns in 1957 and 1964 . . . . .	89
5.5	Storage-Yield Relationships in Susquehanna and Delaware Basin Streams. . . . .	93
5.6	Interbasin Water Transfer Site . . . . .	94
5.7	Interbasin Water Transfer Alternatives. . . . .	95
5.8	Unit Cost Comparison for Water Transfer Alternatives . . . . .	110
6.1	The Market for Property . . . . .	127
6.2	The General Market for Property . . . . .	130
6.3	The Study Area . . . . .	159

LIST OF TABLES

<u>Number</u>		<u>Page</u>
3.1	Ranking Components of a Water Supply System in Order of Increasing Costs. . . . .	19
3.2	Comparison of Regional to Local System Costs for Boalsburg, Pa. . . . .	26
3.3	Comparison of Regional to Local System Costs for Lemont, Pa. . . . .	27
3.4	Reservoir Costs for Two Demand Centers under Individual versus Combined Operation . . . . .	34
3.5	Reservoir Cost for Two Demand Centers under Individual versus Partial Integration. . . . .	37
4.1	Northeast Susquehanna Drainage Basins used in the Firm Yield and Shortage Index Studies. . . . .	55
5.1	Estimated Quantities to be Supplied by Regional Programs. . . . .	85
5.2	Monthly Streamflows during 1957 Drought . . . . .	90
5.3	Monthly Streamflows during 1964 Drought . . . . .	91
5.4	Delaware System Reservoirs and Aqueduct Capacities. . . . .	99
5.5	Costs of Interbasin Water Transfer. . . . .	100
5.6	Marginal Cost of Flood Control in Schemes 1 and 3 . . . . .	112
6.1	Sample Sizes by Property Types . . . . .	161
6.2	Alternate Estimation Equations for Property Values in the Study Area, 1975 . . . . .	163
6.3	Alternate Estimation Equations for Property Values in the Study Area, 1956-1957 . . . . .	164
6.4a	Developing Property Value Indices . . . . .	167
6.4b	Developed Property Value Index . . . . .	167
6.5	Developing Property Value Indices for the Project and Control Areas . . . . .	168
6.6	Developed Residential Housing Value Indices . . . . .	169

LIST OF TABLES

<u>Number</u>		<u>Page</u>
6.7a	Developing Property Subsample Impact Value Estimates . . . . .	170
6.7b	Developed Residential Property Impact Value Estimates . . . . .	170
6.8a	Developing Property Subsample Impact Value Estimate: Adjustment Model . . . . .	171
6.8b	Developed Property Subsample Impact Value Estimate: Adjustment Model . . . . .	171

CHAPTER I  
INTRODUCTION

This paper has been written in view of the growing belief that regionalization is a key solution of American water supply (and wastewater treatment) problems. It is written not only because so many state and federal agencies are suggesting regionalization projects, but also because so many local communities have rejected regionalization plans. This mismatch of thinking between state and federal and local governments may be defeating, or at least deferring, the benefits which many describe regionalization to offer. In fact, these costs are implicit. Explicitly, the mismatch directly costs thousands, maybe millions of dollars, in incalculable monies spent on planning for regionalization and on education and advertising campaigns to insure its success. If regional plans are warranted, then we should reinvest these planning funds and try again. Better research information and educational techniques may proselytize local communities so that they may one day see the benefits to be had. If regional plans are unwarranted, however, the money spent is double damned-- spent without success and on a worthless idea.

We believe that too little research has been devoted to the real questions of regionalization. We don't know enough basic information to be sure that proposed regionalization plans are beneficial. Existing work on regionalization is not extensive and lacks generalization in technical, engineering-economic functions on which regionalization would be founded. In this work, we examine earlier literature applying our ideas to case studies, but we also present generalizations whenever possible.

We find that the evidence on advantages of regionalization is not

overwhelming, that regionalization is not always the solution. There are, however, sufficient benefits from regionalization to warrant its consideration as a policy solution of numerous problems. The study reaches no clear-cut conclusion, no broad conceptual position. The study provides methodological background for anyone considering regionalization in practice.

## CHAPTER II

### BASIS FOR THE STUDY OF REGIONALIZATION

Contemplation of regionalization of water supply and the poor record of implementing it in this country provokes thought about root causes of the problem. Regionalization failure may stem from growing provincialism in which we each irrationally protect our own regional resources to the exclusion of others. If such is the case, then we should bury our dead democratic idealism on which our country previously flourished. We choose not to evaluate this possibility in this report and turn instead to other explanations.

#### 2.1. Experience With Regionalization Planning

Regionalization failure is a rational outcome of individual decisions if, in spite of painstaking analysis of the benefits of regionalization, such benefits as estimated do not, in fact, exist. This would be disturbing evidence that we systematically miscalculate benefit/cost data for water regionalization projects even though we have had a long history and experience with cost/benefit analysis in other water resource projects.

Regionalization failure is also a rational decision outcome if a project is beneficial to the sum of a group of individuals but not separately to a majority (or politically powerful minority) of its members. While a regionalization project may produce more total benefits than costs, it may distribute them in such a way that few get many of the benefits and little of the costs and many get few of the benefits and much of the costs. In this case, planners proposing such programs act as good engineers, producing good and technically beneficial plans, but they act as poor economists, producing plans that very unevenly distribute benefits and costs.

We have little opportunity to evaluate which of these possible causes accounts for existing regionalization failure because regionalization's success has been so limited that there are too few implemented cases, especially in humid areas, that we cannot calculate the actual level and distribution of resultant benefits and costs. Regionalization advocates point to the success in regionalizing the water industry in Great Britain where the number of water planning districts was recently greatly reduced. This show piece, however, has had a significant impact only on administration and regulation of the English water delivery system, and has had not much effect on integration of the actual operations of local systems. English regionalization has been set back at the same time, by the evidence presented by Warford (1968). He analyzes the implicit regional subsidization of rural areas and, considering costs of other public services and moving costs, he suggests that it is more efficient to relocate individuals from smaller or scattered developments into denser clusters than to integrate their water systems. This form of regionalization is clearly not what American water authorities have advocated, but it usefully distinguishes between regionalization, moving people to water, and regionalization, moving water to people. The latter takes population locations as given. We must be careful in defining regionalization and associated economies of scale on which regionalization is based. Economies of scale, reported generally throughout the water supply literature, are encountered, as Warford rightfully demonstrates, by increasing the population within a given residential district (holding area constant). To generalize from these findings of scale economies to recommendations of regionalization is dangerous. Regionalization of existing communities increases the service

area and presents the difficulty, of course, that we simultaneously change two variables. That economies of scale hold for regionalizing existing communities is problematic, and needs more study.

There has been regionalization in the United States. Modesto and the Chino Basin in California and Seattle-Metro in Washington are regionalization examples, but these have involved water quality as well as water quantity and there is difficulty in separating the two issues. The Chino Basin and Modesto projects were voted upon by residents. Analysis of differential voter response among sub-regions comparing estimated benefit/cost information, stratified by sub-region, would yield fruitful information. This has been done elsewhere by Abt Associates (1971), Radosevich (1975), and the Advisory Commission on Intergovernmental Relations (1965), and was considered here, but the findings would be highly specific to the case study and would yield little generalization about regionalization in other areas. The Seattle-Metro project in particular, however, supports a hypothesis that regionalization failed because of distributional inequity. Seattle regionalization was once rejected and subsequently passed under conditions substantively changed only with regard to distribution, making the second project more beneficial to the outside central city areas and less (relatively) to the central city.

We find in other areas of this country that regionalization has failed through institutional rigidities. Birmingham, Alabama, for example, has for a number of years considered regionalization, and the Birmingham Water Works, in fact, is serving somewhat in the capacity of a regional supplier. It does so, however, only with financial constraints which limit its optimal size. This is typical throughout Alabama and we consequently find

over 1,400 different suppliers operating in the State. This is far fewer than ideal. The operational and institutional constraint in Alabama is a law requiring forfeiture of capital facilities constructed outside the primary jurisdiction boundaries whenever capital indebtedness on facilities outside the primary jurisdiction is retired. Regionalization occurs but not at full efficiency because systems which regionalize, over-capitalize and over-amortize capital so as to avoid capital forfeiture. Like Seattle, this is frequently a central city/suburb confrontation.

The same is true in other areas of the country. New York, a prime focus of the Corps NEWS program, has hesitated on regionalization because it does not want to give up (perceived) previous autonomy. Yet, needing the water, the City feels ambivalent. The New York Times editorial, "Thirsty Metropolis" (March 18, 1975) chides:

Bearing this possibility (of drought) in mind, New Yorkers must heed the latest recommendations of the Temporary State Commission on the Water Supply Needs of Southeastern New York. Just one year ago, the commission proposed creation of a new regional authority to develop and manage water supplies for the Southeastern area of the state. That sensible proposal was rebuffed by Mayor Beame and other city officials as an infringement on "home rule" and an alleged attempt to "confiscate" the city's own highly developed water system.

. . .

A common feature to both (regionalization) plans is a requirement that the city install universal metering, which the commission estimates would result in a 15 percent saving, or about 240 million gallons per day. New Yorkers, who have been rejecting metering for a century, must recognize that they are not going to gain access to necessary new sources of water supply under any schemes as long as upstate communities where new facilities would be located are convinced -- and justly so -- that the city is wasting the water it already has.

Residents outside the center city region see New York City demands for their water as a means of capitalizing on fortuitous natural resource endowments. They also see these demands as threatening. An upstate editorial from the Middletown Times Herald-Record, "Involuntary Servitude" of March 28, 1975, argues for regionalization primarily as a means of reinstating upstate's lost equity:

Too many of this region's natural resources -- water, land, scenery -- have been indentured to metropolitan New York. We have been given no say during the systematic seizure.

. . .

We expect to share some of the grueling problems of New York City by sharing our resources, but we also have -- or should have -- the right to help determine if, how and when our resources are to be tapped.

With that in mind, we unhesitatingly choose regional control of southeastern New York's water supply. A temporary state commission has presented the two choices to the state Legislature.

The regional plan, as we see it, would give this region control over water resources, including those earmarked for New York City. Such control has been lacking for too long.

The proposal could lead to mandatory water metering in the city, shamefully avoided for decades. And it would remedy the disgraceful plundering of the Neversink and Delaware rivers by establishing release requirements from waters further upstate.

The state agency idea, on the other hand, would change little, leaving New York in command of this region's water supply.

Michigan presents the same type of problem in a water supply-related project, the Corps' water treatment sludge disposal project at Raisinville. Those who have resources protect them because they are (or at least feel they are) inadequately reimbursed. On Sixty Minutes, "Here Comes the Sludge," CBS correspondent Morley Safer, speaking for the rural residents, converses with the Monroe, Michigan city spokesman, City Director, Leonard Leis:

SAFER: I get the feeling a lot of country people - not only here, but in other parts of the country - (feel) about this stuff, that sludge, rubbish, garbage, that's a city problem, that's an urban mess that they make themselves: Don't dump it on us. Why dump it on us?

LEONARD LEIS: Well, I can't agree with them at all, because many people on the farms are coming into town now and making their livelihood here. Many in the same mills that are having the problem with this sludge disposal right here in the city of Monroe, and the rural people are going to have to accept their responsibility in the disposal of sludge.

New Jersey has so recognized the impacts of regionalized water programs -- especially sewerage projects constructing interceptor sewer lines -- that they have stated:

Today, outside of the general economy, sewers are the critical ingredient and the guiding force for growth in New Jersey. As the cost of land and construction rises, more townhouses and multi-family units will be built in proportion to single family homes. Sewers are essential for this higher density construction. As a result, the role of sewers as a growth determinant will become even stronger in the future.

One of the most important impacts of regional sewer development is its effects on land values. Other benefits of public sewerage are paid by user charges, but the land value benefits are traditionally uncompensated with any kind of cost to the user. This occurs because property taxes are generally insensitive and unresponsive to the magnitude of the property value changes. The New Jersey study suggests that these land value changes are unanticipated, windfall gains.

The expenditure of vast amounts of public funds has resulted in the windfall benefits to landowners in the form of increases in property value. At the same time, the public does not recoupe this unearned increment of value obtained at its expense.

These represent distributional inequities of the system; few individuals fall heir to the windfall profits and most pay user costs equal to their own full benefits. Regardless of the total relative benefits and costs, it is no wonder individuals reject schemes that embody so little equity.

The report of Urban Systems Research and Engineering, Inc. to EPA shows further that interregional competitiveness to obtain interceptor sewer development funds (so as to gain regional economic development capital) has led many projects to anticipate more than 2,000 years of population growth. This result is clearly unwarranted with any reasonable discount rate but results, in part, from lack of consideration of equity in funding and financing sewer systems. The Council on Environmental Quality made this comment, suggesting further that the impacts of large regional projects greatly affect urban, suburban and rural populations differentially:

The location and rate of extension of interceptor sewer lines through previously undeveloped areas seem to have more impact on land use than any other set of decisions on wastewater facilities . . .

A related land use impact caused by large interceptor sewers is their tendency to be designed to run for long distances between existing towns before reaching the treatment plant. Such lines open up large areas of what may have been previously undeveloped land between the towns. While this may be in line with overall regional land use planning, it could also run counter to desirable development patterns, particularly if sewers are placed only with an eye toward wastewater treatment efficiency.

In one recent case, a proposed interceptor was slated to run through a large undeveloped coastal area of Delaware that was on the state plan for eventual purchase as recreational land. The proposal would have used public funds to build a sewer that would have substantially raised the purchase cost of the land to the public.

We may ultimately come to view regionalization failure as a result of urban/suburban jealousy, disparities and inequities that have long been with us.

## 2.2. Efficiency and Equity; Integration and Extension

The observations of section 2.1 together with some amount of introspection suggest that we divide our attention throughout the remainder of this report between the issues of efficiency and equity. We expect that regionalization is sometimes rejected in practice because it is not efficient, that it does not provide cost savings relative to individual, independent systems. We expect regionalization, at other times, has been rejected because it was not equitable enough to attract a sufficient number of supporters to gain success. We begin with these possibilities as our study hypotheses but we believe that lack of equitability is more often at fault when regionalization provides new community growth (service extension) than when regionalization integrates existing systems. We do justify the contention, in fact, that extension regionalization is more efficient, *ceteris paribus*, than integration regionalization (section 3.4.6, below). This is a basis for limiting our analysis of extension to equity.

In fact, efficiency and equity are not as easily separable as traditional theory suggests, the latter calling for the separation of the efficiency

(allocation) and equity (distribution) functions of government.\* Society may approve inefficient plans when the few existing net benefits are inequitably distributed to the politically powerful. Perfectly efficient and equitable plans may be rejected precisely because they impose fair distributions. We cannot evaluate regionalization proposals first for efficiency and second for equity. Both simultaneously affect social acceptance. Nevertheless, we do limit analysis primarily to efficiency in regional integration and to equity in regional extension.

### 2.3. What Lies Ahead

With the rationale and limitations of the scope of this report set, we proceed to the tasks at hand. Chapter III takes up regional integration, evaluating small, rural suppliers. Enmeshed in this chapter, section 3.4.6 shows that regional extension is more efficient than regional integration, a result already noted. Chapter IV evaluates regional integration under water shortage costs, hydrologic risk and uncertainty. This is a stronger motivation for regionalization than those noted in Chapter III but, given high correlations of intrabasin hydrologic flows over time, only few areas will find such regionalization attractive. Chapter V analyzes large scale interbasin transfer and provides a clear motivation for (Eastern) regional integration. Lack of interbasin hydrologic variation weakens the overall significance of such transfer.

Chapter VI evaluates the impacts of regional extension, taking water supply and sewerage service simultaneously because these services are

---

\*See Musgrave (1959) for a general treatment and with specific reference to regional and water problems see also Mera (1967) and (1973), Krouse (1972), and Fritz (1976) and (1976).

otherwise difficult to separate. Chapter VI focuses on the housing market, for reasons explained there, and justifies wide variation in measured property value changes -- a common malady of many early studies. The material in Chapter VI shows distributional inequity to be a source of regionalization failure. Chapter VII summarizes and concludes the report. It offers some abbreviated policy prescriptions for establishing successful regionalization.

## CHAPTER III

### REGIONALIZATION OF EXISTING SYSTEMS

Before starting a study on the feasibility of regionalization of water supply or waste disposal systems, the question must be answered: Who is promoting regionalization and for what reason?

In the first place, plans to encourage regionalization of any system of utilities originate at federal and state regulating agencies. Clearly it is much simpler for a state department of Environmental Resources to supervise a few dozen utilities than several hundreds or thousands.

Secondly, the push for system integration between several neighboring communities usually comes from the largest of the towns. Whether this tendency to expand really has economic reasons or political ones is hard to say, often the mere existence of a small village muddling along independently inside a metropolitan area is a particularly sore thorn in the eye of big brother without really constituting any economic threat or disbenefit.

Whatever the reasons of a state regulating agency or a larger community may be for proposing regionalization of utilities, they per se are not likely to have a positively persuasive effect on the smaller communities to be annexed. Small authorities are likely to give up their autonomy only when visible benefits or savings through regionalization can be demonstrated. These benefits could in a few cases consist of improved water quality or better sewage treatment, but in most cases money speaks in a much more convincing tone. Thus, an old dilapidated water supply system in dire need for a

complete overhaul may find the offer of connecting to a nearby regional system highly attractive, or a State Health Department ordinance requiring a sophisticated water filtration may absolutely force the smaller communities into regionalization.

Finally, in areas prone to water shortages, it may be found that only a regional system has the political and financial strength to secure the additional water resources needed to satisfy the growing demand.

### 3.1. Principle of Economies of Scale

Economies of scale are probably the prime argument offered in favor of regionalization. The old saying that "two people can live cheaper than one" is rephrased as "2 mgd of water can be collected, treated and delivered at a cost less than twice the cost of 1 mgd".

Gotzmer (1976), in a thesis submitted as interim report of this project, presented a thorough description of short and long run cost curves and the theory of economies of scale. In Figure 3.1a, a hypothetical curve of total variable cost TC is shown, increasing at a decreasing rate up to the point of inflection, beyond which it increases at an increasing rate. The total cost can be expressed as the sum of total fixed cost TFC and total variable cost TVC.

Figure 3.1b introduces the concepts of the average total cost, average variable cost and marginal cost corresponding to the total cost curves in Figure 3.1a. These latter terms are preferred by the economist as measures of cost effectiveness of incremental investments.

Figure 3.1a and Figure 3.1b, together, show a relationship known as the total-marginal relationship. "When a total curve is increasing at an increasing rate, its corresponding marginal curve is rising; when a

### COST CURVES

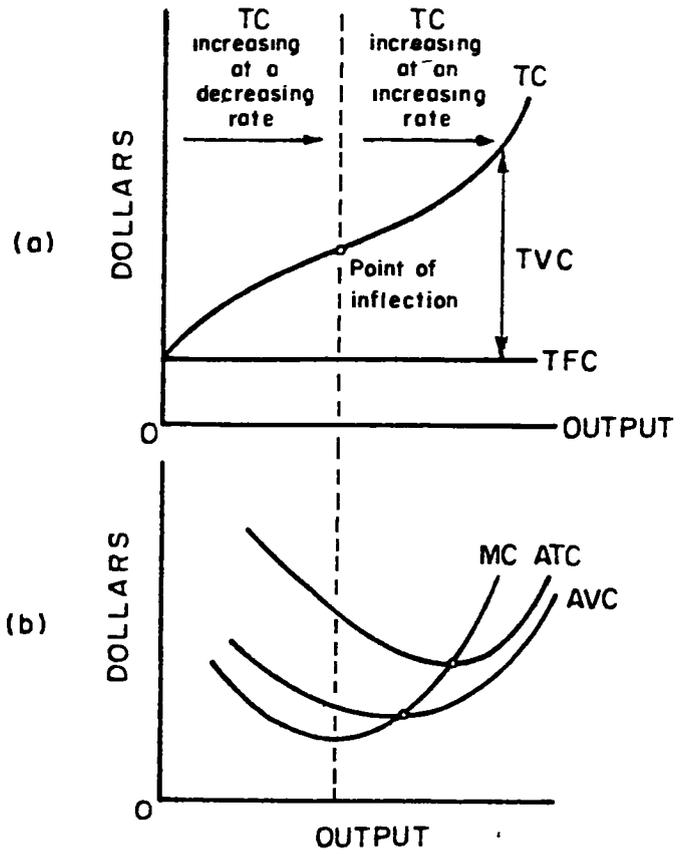


Figure 3.1 Typical Cost Curves (after Spencer, 1974)

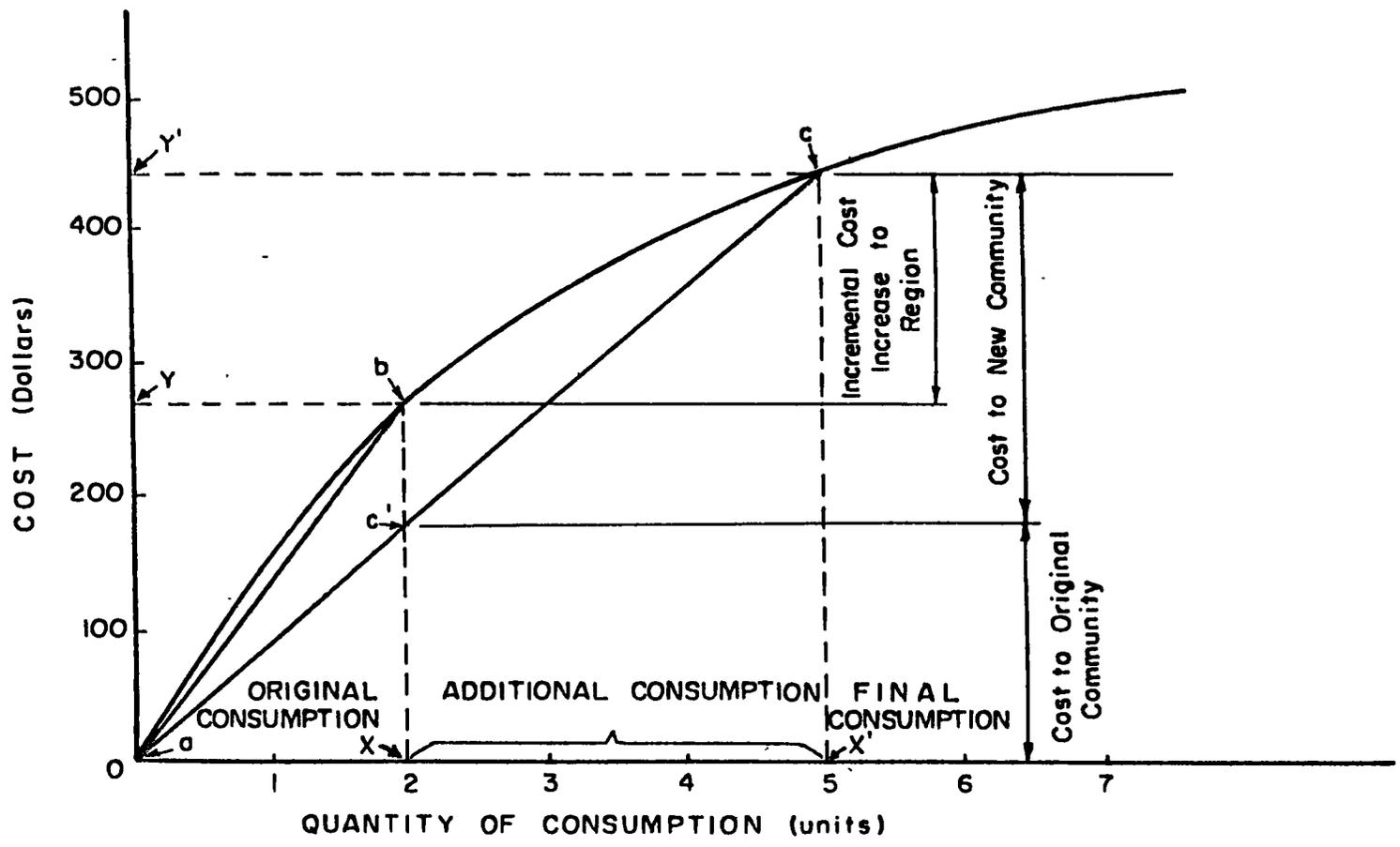


Figure 3.2 Cost Curve for a Small Community

total curve is increasing at a decreasing rate, its corresponding marginal curve is falling; and when a total curve is increasing at a zero rate, as occurs when it is at its maximum, its corresponding marginal curve is zero." At the point of inflection on the TC curve, the MC curve is at a minimum. The MC and the ATC are equal at the output where the ATC curve is at a minimum point. The corresponding point on the TC curve is the point of tangency on the TC curve of the ray through the origin.

Figure 3.2 could be used to describe to a community the advantages of utility expansion, provided the costs follow the curved line traced from point a through b to c and continuing. Clearly a system originally scaled to provide 2 units of water (or any other consumable good) at a cost Y would benefit if it could expand to deliver, say 5 units. The average costs  $Y^1/X^1$  of the expanded system are considerably lower than the original average cost  $Y/X$ . Even lower is the marginal cost  $\frac{Y^1 - Y}{X^1 - X}$  of the expansion. If the supply system expansion is due to the regional integration of several neighboring communities, the low marginal cost would constitute the benefit to the region.

If the managers of the original system were really eager to persuade neighboring communities to join, they could offer the three additional units at a price equal to the marginal cost. Such an arrangement would however be unfair to the consumers of the original system which would continue to pay the high average price  $Y/X$  and not benefit from the expansion. Such a scheme could also, in spite of the strong enticement, delay the regionalization process if several neighboring consumers are involved in the negotiation, because each consumer would know that the last one to join the regional system would be charged the lowest marginal cost.

A more equitable scheme, which would allow early and late joiners equal benefits of the regionalization effort, is one in which all consumers are charged a price equal to average costs, which would decrease every time a new consumer joins the system, until a point is reached at which the marginal costs exceed the average costs.

### 3.1.1 Average and Marginal Cost Pricing

This pricing by average costs is realistic of current practice, but it, of course, ignores the optimal pricing of marginal cost in which case each community, would be charged an equal price equivalent to the common marginal cost (abstracting from differentials in costs among systems). Under this type of pricing, each community would profit from system expansion only up to the point where marginal costs were minimized, and not as above where existing communities press for expansion to minimum average costs. At the different optima, with average cost pricing the ultimate solution, given sufficient forces for regionalization to push total quantity to minimum average cost, more approximates a perfectly competitive solution than does the marginal cost solution. The average cost pricing solution mimics the perfectly competitive solution in setting output at the minimum cost quantity, putting price equal to both marginal and average costs because of the equality of the latter two at minimum average cost, and leading to normal profit levels since average costs and revenues would also be equal. Thus, despite the usual disclaimers that average cost pricing is suboptimal, in this case it is well warranted.

### 3.2. Economies of Scale in the Real World

After acquainting himself with the economic theory of economies of scale, Gotzmer proceeded to compile published cost curves and to interview local officials about their experiences with costs of expanding systems.

Table 3.1 Ranking Components of a Water Supply System in Order of Increasing Costs.

Curve Number	Corresponding Curve Definition	Type of Curve
2	Transmission Pipe Line Construction Cost	Stepped
6	Treated Water Pumping Station Construction Cost	Straight-Lined
6b	Pumping Station Other Than With Treatment Plant	Straight-Lined
6a	Pumping Station Integral With Treatment Plant	Straight-Lined
3	Pipe Line Pumping Station Construction Cost	Straight-Lined
10	Intake and Pumping Station Construction Cost	Straight-Lined
7	Pumping Power Cost	Straight-Lined
1	Well Construction Cost	Straight-Lined
9	Pumping Operation and Maintenance Cost Exclusive of Power	Curved
4	Raw Water Storage Construction Cost	Straight-Lined
5	Treatment Plant and Storage Construction Cost	Curved
8	Water Treatment Operation and Maintenance Cost	Curved
11	Reservoir Construction Cost	Curved

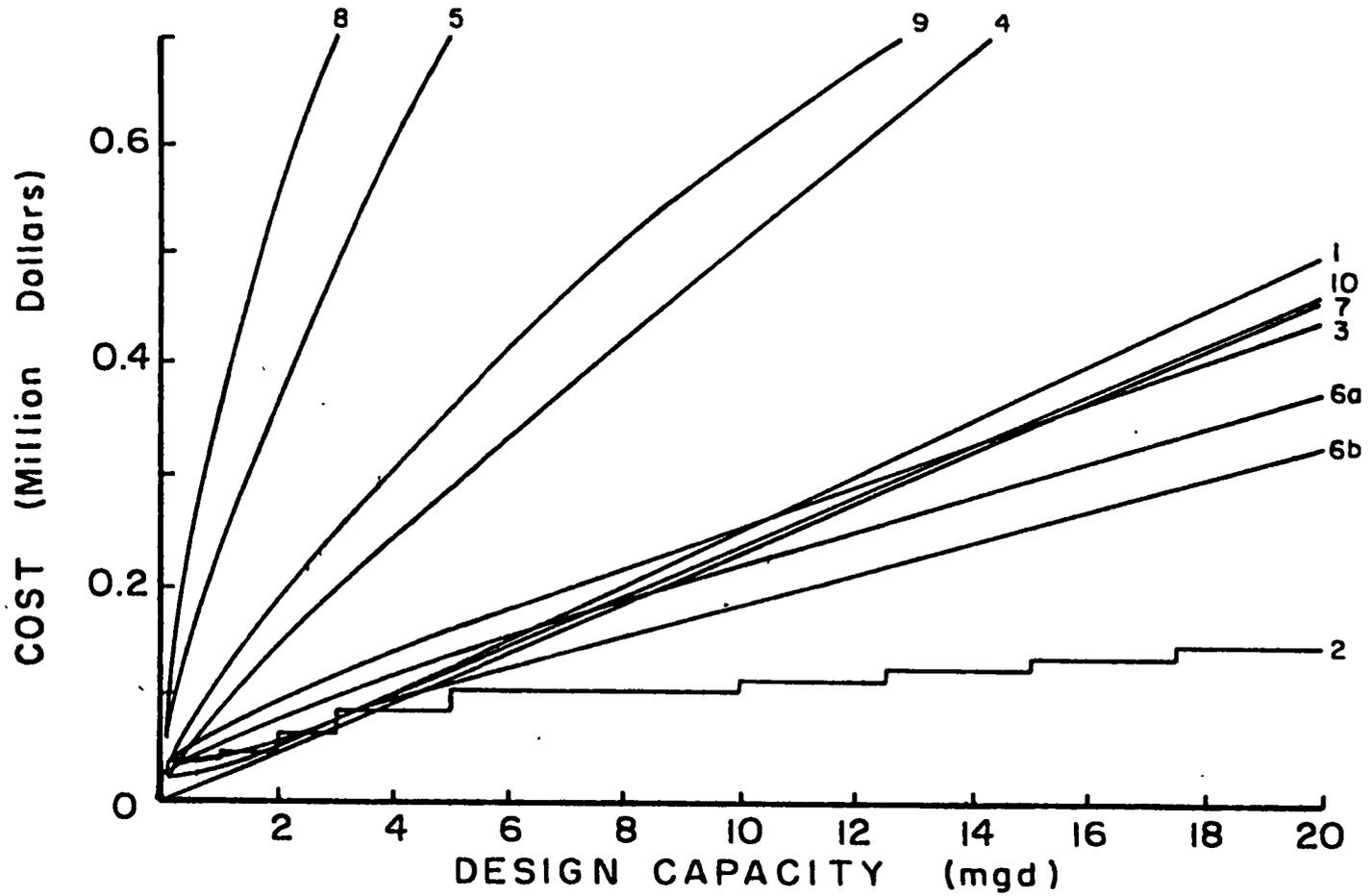


Figure 3.3 Cost Curves of Elements of a Water Supply System, 0 to 20 million gallons per day (after Black and Veatch, 1963)

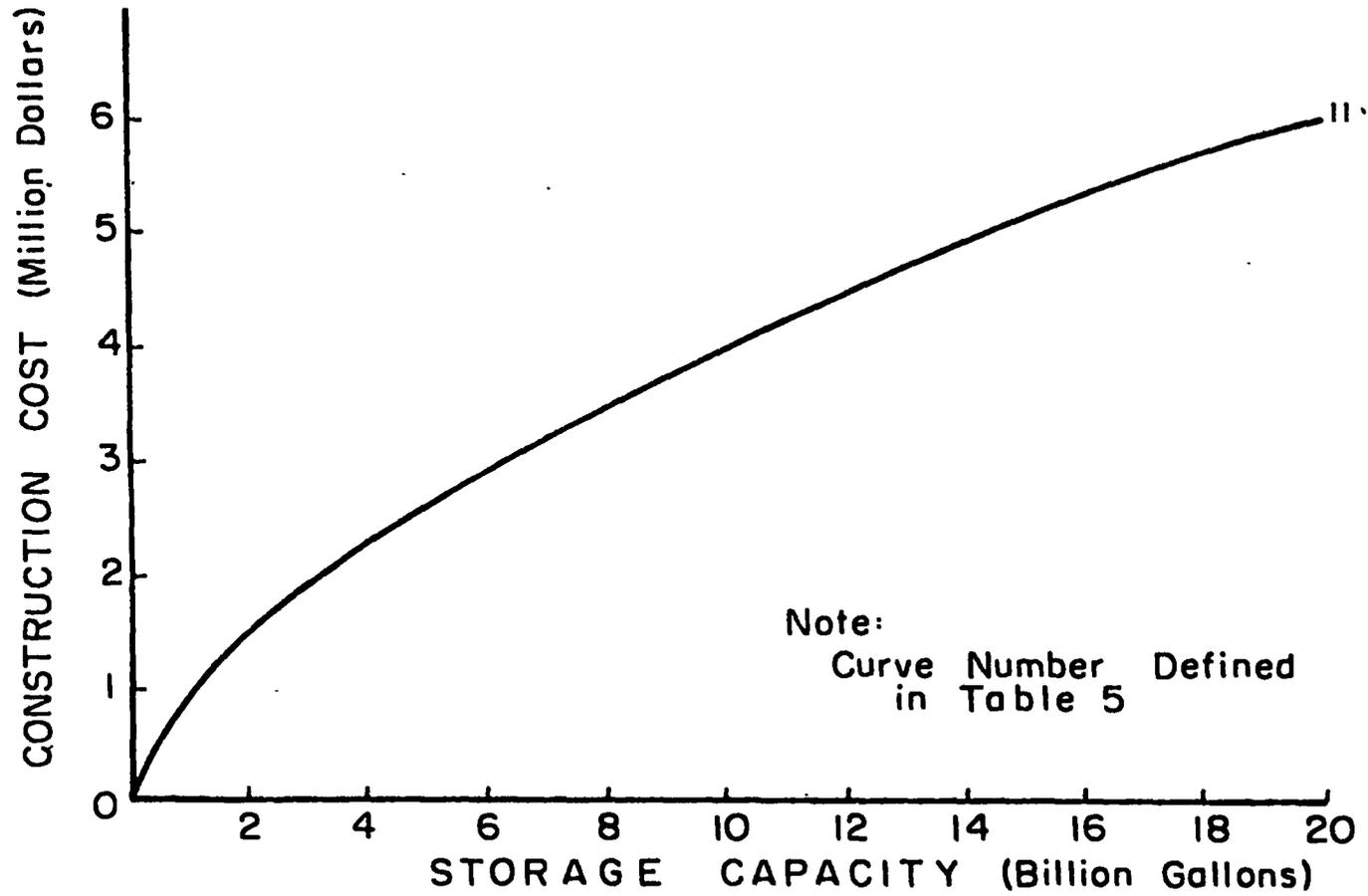


Figure 3.4 Construction Cost Curve for Impounding Reservoir,  
0 to 20 billion gallons (after Black and Veatch, 1963)

Table 3.1 and Figure 3.3 do not paint as rosy a picture for regionalization as the study of economic theory might have promised. With the exception of storage reservoirs (Figure 3.4) and treatment facilities, little evidence of economies of scale could be found. Particularly the ground water well and pump system which supplies the majority of the water for State College, Pennsylvania (the hub of the micro-scale case study) was reported to have a cost practically proportional to supply capacity. At least in principle the average operation and maintenance costs should decrease with increasing number of wells, but we found water authority officials to suspect, pragmatically, that an expansion of the system might result in an increased bureaucracy, thus offsetting any gains achieved through more efficient maintenance.

An even stronger argument against water supply regionalization was presented by water authority officials in Boalsburg, a 3,000 resident village near State College, which has been approached repeatedly about connecting to the State College well field. In this community, the general maintenance of township roads, traffic signs and lights, snow plowing and weed mowing as well as the maintenance of the water reservoir, pipe lines, valves and hydrants was done by a crew of three workmen. Elimination of the local water system (a small forest stream, an 860,000 gallon reservoir and a 3-mile 10-inch pipeline) would not reduce the size of the general maintenance crew. Furthermore, a major part of the computerized accounting and billing service is presently being performed voluntarily by one of the honorary members of the township water authority. The present estimated safe yield is roughly 3 times the average consumption. The only measure to force Boalsburg to join a regional water system would

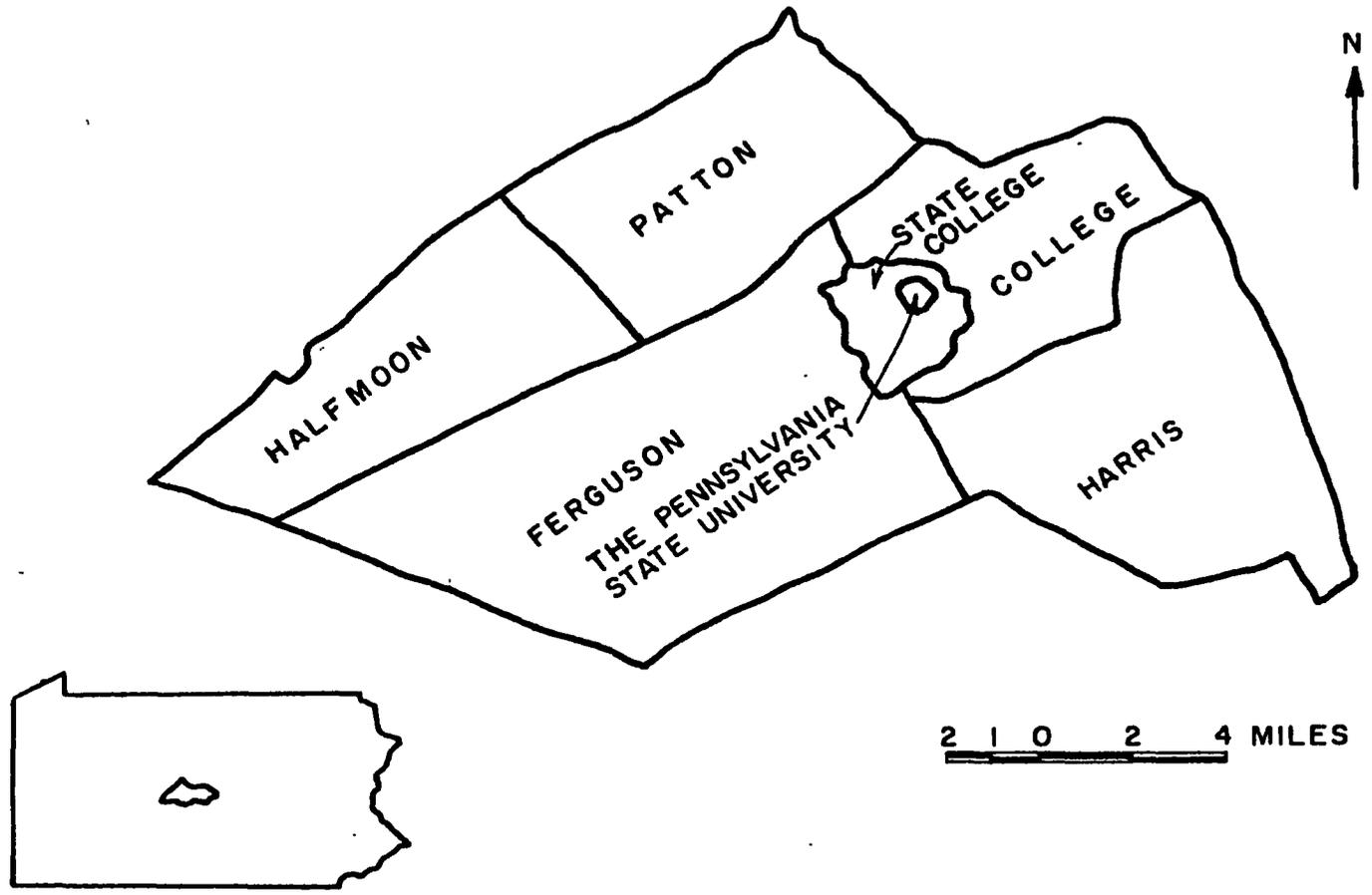


Figure 3.5 Location Map of Centre Region and Its Townships

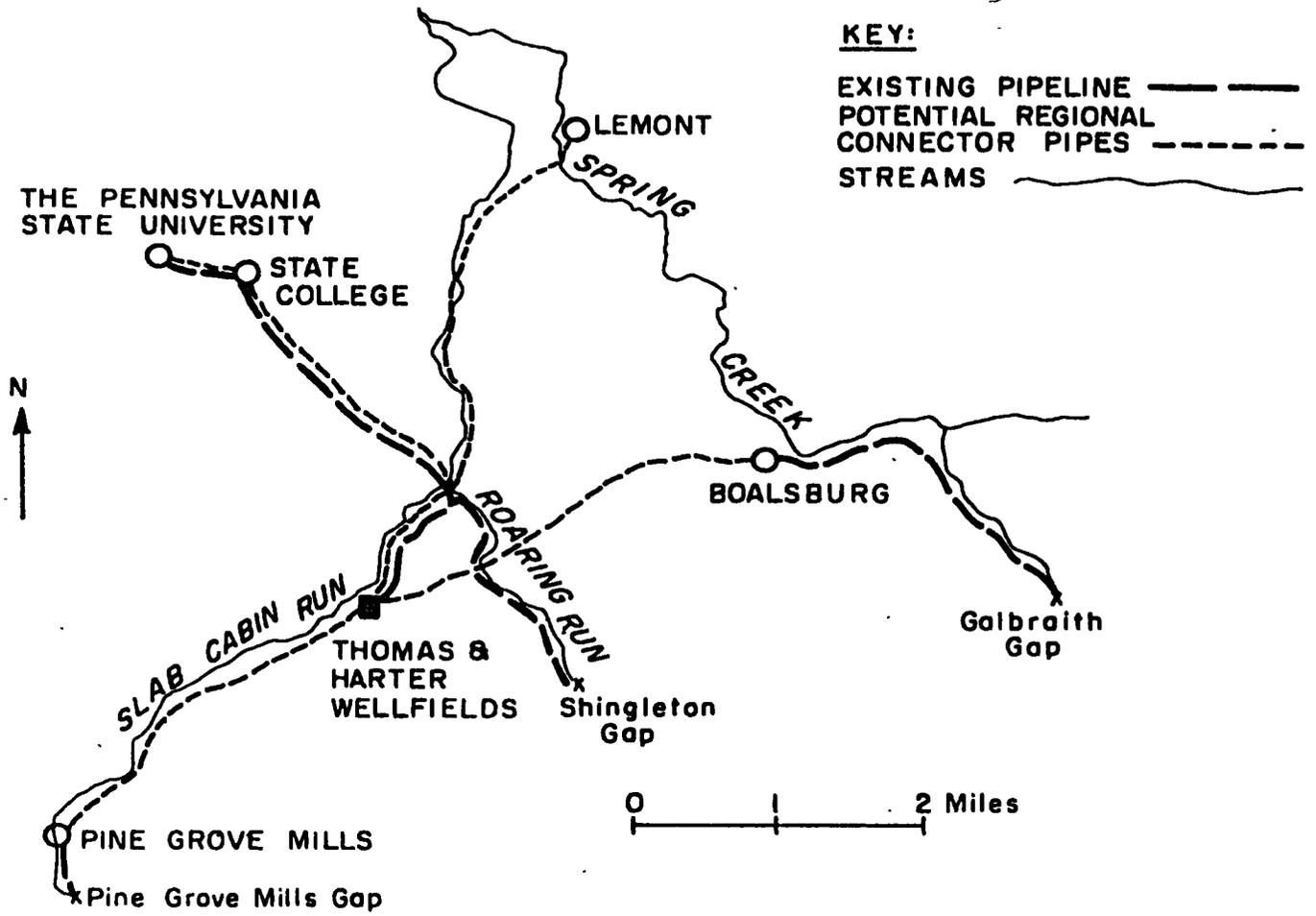


Figure 3.6 Location Map of Potential Centre Region Water Consumption Centers

be a state or federal law mandating a highly sophisticated water treatment process for all public water supply systems.

### 3.3. Micro-Scale Case Study

The Centre Region around State College was chosen as the case study site for the micro-scale study phase. The reason for the site choice and the entire micro-scale study was to make use of readily accessible data and information on the problems and prospects of regionalization. This experience would then provide the investigators with a feel for the real life problems involved in regionalization efforts on a large scale, which tend to be treated overly impersonally and analytically.

#### 3.3.1. Description of Centre Region

Centre Region is located in the south-central portion of Centre County in the northern portion of the Nittany Valley and is approximately at the geographical center of Pennsylvania (Figure 3.5). Geographically, Centre Region is a "part of the Ridge and Valley Province, a rather unique series of parallel mountain ranges and valleys running east of the Allegheny Front. The Region is drained by the Susquehanna River Basin," (Centre Regional Planning Commission, 1974).

#### 3.3.2. Communities Selected as Regionalization Candidates

A total of five communities from the municipalities of Centre Region were selected for consideration in the regionalization study: State College, The Pennsylvania State University, Boalsburg, Lemont, and Pine Grove Mills (Figure 3.6). The following is a brief description of the existing water systems in each of the five communities.

#### 3.3.3. Comparison of Local vs Regionalized Water Supply Systems

Gotzmer (1976), in his M.S. thesis submitted an Interim Report for this research project, described in detail the present supply systems of

Table 3.2 Comparison of Regional System Costs to Local System Costs for Boalsburg

A. Regional System	COSTS (dollars)	
	1970 Demand (83.2 mg/yr)	1990 Demand (219 mg/yr)
Purchase of Regional Water (Slope of Figure 27)	43,300	113,900
Pipe Construction	190,300	190,300
Pipe O & M & R-O-W	7,400	7,400
Booster Pumps	9,100	9,100
Power and Energy	34,300	54,100
Pump Station, Installed + O & M	16,000	16,000
<b>TOTAL:</b>	<b>300,400</b>	<b>390,800</b>

B. Local System	COSTS (dollars)	
	1970 Demand (83.2 mg/yr)	1990 Demand (219 mg/yr)
<b>Construction Costs:</b>		
Reservoir	52,500	138,100
Liner Preparation	12,300	32,300
Liner	4,800	12,600
Modifying Drains	1,100	2,900
Fence	4,000	10,500
Pipes (From Calculated Costs)	190,300	190,300
O & M Costs	157,400	157,400
<b>TOTAL:</b>	<b>422,900</b>	<b>554,600</b>

Table 3.3 Comparison of Regional System Costs to Local System Costs  
for Lemont

A. Regional System	COSTS (dollars)	
	1970 Demand (186.2 mg/yr)	1990 Demand (365 mg/yr)
Purchase of Regional Water (Slope of Figure 27)	96,800	189,800
Pipe Construction	242,700	242,700
Pipe O & M & R-O-W	10,900	10,900
Booster Pumps	6,400	6,400
Power and Energy	29,600	30,100
Pump Station, Installed + O & M	16,100	16,100
<b>TOTAL:</b>	<b>402,500</b>	<b>496,400</b>

B. Local System	COSTS (dollars)	
	1970 Demand (186.2 mg/yr)	1990 Demand (365 mg/yr)
<b>Construction Costs:</b>		
Reservoir	23,400	45,900
Well	19,600	38,400
Pumps	6,500	12,700
Treatment	1,400	2,700
Pipes (From Calculated Costs)	22,300	22,300
O & M Costs	230,000	230,000
<b>TOTAL:</b>	<b>303,200</b>	<b>352,000</b>

the five communities singled out above. Their relative locations and the potential connecting pipelines are shown in Figure 3.6. The results of the technical and economic comparison of independent versus regionalized systems will only be summarized here to avoid duplication with the content of the interim report.

Present and estimated future water needs were well documented in everyone of the communities, which made it relatively easy to size the connecting conveyance lines and the required well field expansion at the main regional water source. More difficulties arose in the cost estimates. The communities supplied cost data for their individual systems, but the costs for the alternative regional systems had to be taken from generalized cost curves and equations cited by Aron et al. (1974) and Black and Veatch (1963).

Two of the cost comparisons are summarized in Tables 3.2 and 3.3. According to these tables, Boalsburg should consider tying up with the regional system whereas Lemont should not. The fallacy in this conclusion lies in the fact that the Boalsburg reservoir and the pipeline from the reservoir to the village are already in place and have thus become an irreversable fixed cost. Therefore, the conclusion would have to be revised to read that Boalsburg should consider regionalization if at any time their present system needs a complete replacement. Further, it was mentioned in section 3.2 that the operation and maintenance costs, even though presently charged to the water supply system, could probably not be eliminated by switching to another water system because the maintenance crew also maintains the township roads and yards.

#### 3.3.4. Public Reactions to Regionalization Proposals in Small Systems

The conclusion of the micro-scale case study was that highly site-specific and up-to-date cost estimates would be needed to assess realistically the economic net benefits or disbenefits of water supply regionalization. It was recognized by all of the small independent water authorities that if federal or state regulations some day would mandate a sophisticated water treatment process, centralization into one regional authority would be the only feasible solution.

The public reaction or attitude toward regionalization of small water supply and consumption centers is probably more important in the decision making process than the economic considerations, particularly when the latter ones include as much arbitrary accounting as tends to be done in small communities.

The basic reaction by residents and officials of small communities is one of suspicion and mistrust. The benefits to be gained through regionalization would have to be extremely convincing to persuade the smaller communities to agree voluntarily to system integration with a regional system.

A factor to be explored in the following chapter is the one of a water shortage threat as an incentive to regionalization. Among small systems of the humid east, however, it seems to be rather futile to look for threatening drought conditions. Reservoirs are seldom more than holding ponds storing 3 to 5 days of water supply, and are more frequently used when flood conditions in the supply stream result in excessive turbidity of the natural supply water.

Thus the importance of reservoir requirements to assure some minimum safe yields, and the incentive to increase the system size to guard against the threat of a drought are issues which apply much more to larger than smaller systems. These items will be dealt with in the following sections and in Chapter IV.

#### 3.4. Systems Requiring Reservoir Capacities to Firm Up Their Water Supply

As mentioned in the previous section, small demand centers in the Humid Northeastern United States do not tend to require any substantial storage capacity to carry them over a dry season. Considering that, aside from water treatment, reservoir costs are the only ones exhibiting pronounced economies of scale, it will be necessary to shift to medium or large systems to find a realistic need for regionalization.

##### 3.4.1. Generalized Reservoir Storage Requirements

The reservoir storage capacities required to assure a community of a given minimum safe yield depend of course on the particular climatic character of a region and on the steadiness of the streamflows. Ephemeral Western streams can run completely dry for months, followed by major flood flows, whereas Eastern streams are mostly perennial and are supported by a substantial steady baseflow. Reservoir requirements to assure a given safe yield therefore can be much smaller in the latter regions.

In order to avoid the need for specific numerical design examples, and to provide guidelines of more generality, the construction and use of dimensionless graphs should be encouraged wherever possible. Black and

Veatch (1963) produced the curve shown in Figure 3.7, a plot of the  $R/Q$  versus  $C/Q$ , in which

$R$  is the dependable annual yield required

$Q$  is the average annual streamflow, and

$C$  is the reservoir storage capacity assuring the relative yield  $R/Q$

$R/Q$  is completely dimensionless, whereas  $C/Q$  has the dimension of

1 year of time. The volume terms in  $R$ ,  $Q$  and  $C$  have to be identical

and could thus be acre-feet, million gallons or billion gallons.

The plot, which reportedly originated from studies by the United States Geologic Survey, shows large increases in required storage to satisfy a rise in relative demand  $R/Q$ . The curve is useful to demonstrate the principle of economies of scale, but should not be used in design without its agreement with the hydrology of the stream chosen as the main water source.

In the following sections the Black and Veatch yield-capacity curve will be used in conjunction with the reservoir construction cost curve to show hypothetical situations in which two demand centers, served by two streams of different sizes, have the option of developing their separate sources individually or joining into one regional system.

#### 3.4.2. Complete Integration of Two Supply Systems

The first type of hypothetical example used in the application of Figures 3.4 and 3.7 involve the case where the complete regionalization of two communities may take place. Two communities, A and B, were assumed, each with a given average annual consumption rate. Each drew water from its respective surface stream, a and b, with average annual

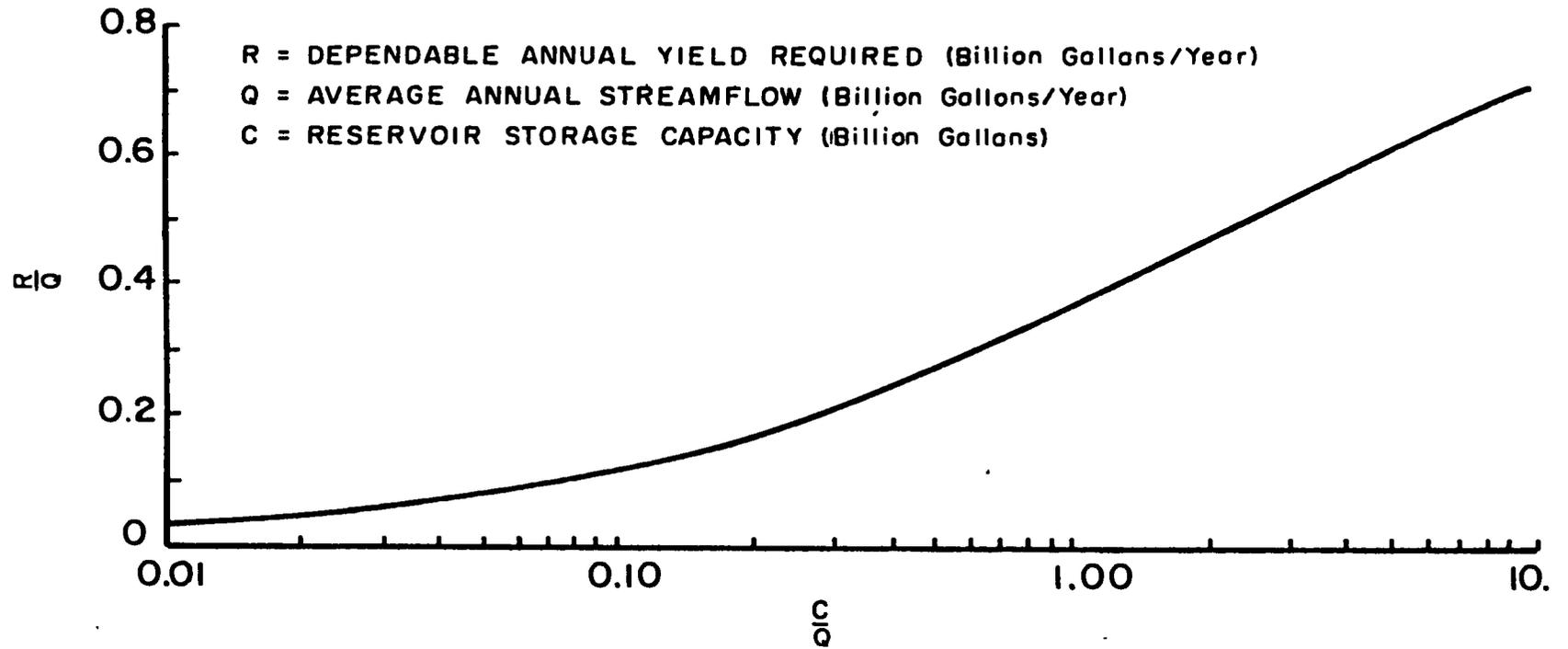


Figure 3.7 Storage-Yield Relationship for Impounding Reservoirs (after Black and Veatch, 1963)

streamflows  $Q_a$  and  $Q_b$ . Each community has its respective required yields,  $R_a$  and  $R_b$ . Stream b was assumed to have the larger flow. Thus complete regionalization would involve community A as well as B receiving its water from stream b.

Table 3.4 illustrates a comparison of the individual operation of the two communities to a combined operation. Comparing individual operations, it is obvious from the table that community A would have to provide for a reservoir with a much larger capacity than community B, even though B consumes 2.5 times as much water.

Since the average annual flow of stream b is much greater than that for stream a, it appears worthwhile to consider joining systems A and B, with stream b supplying the water. As a result, a 14 bg reservoir is needed on stream b as compared to a 13 bg reservoir on stream a and a 7 bg reservoir on stream b. The resulting savings to the regional system is 2.95 million dollars, which can be applied against the cost of pipeline installation.

Various cases, similar to the one above were considered. For example, with  $Q_a$ ,  $Q_b$ , and  $R_b$  held constant, the value of  $R_a$  was varied through a range of required safe yields. Then, a new  $R_b$  was assumed, and  $R_a$  was varied again. The values of  $Q_a$  and  $Q_b$  were then changed and the above variations were repeated. The result was a comparison of  $R_a$  values to savings to the system.

Figure 3.8 shows the results of one such case where  $Q_a$  and  $Q_b$  were held constant and  $R_a$  and  $R_b$  were varied in the method explained above.

Table 3.4

RESERVOIR COSTS FOR TWO DEMAND CENTERS  
UNDER INDIVIDUAL VERSUS COMBINED OPERATION

	I	II	Combined
Community	A	B	A + B
Source	a	b	b
R, bg/yr	4	10	14
Q, bg/yr	10	100	100
R/Q	0.4	0.1	0.14
C/Q = f(R/Q), from Figure 3.7	1.3	0.07	0.14
C, bg	13	7.0	14
Cost, million dollars, from Figure 3.4	4.6	3.2	4.85
Under proportional cost sharing:			
Cost to A, million dollars			1.38
Cost to B, million dollars			3.47
Savings to Region:			
$A_{\text{single}} + B_{\text{single}} - (A + B_{\text{combined}}) =$			
$4.60 + 3.20 - 4.85 = 2.95$			

Similar computations were made for other combinations of  $Q_a$  and  $Q_b$ , and several observations were made from these studies:

1. As the value of  $R_a$  increases, the savings to the region increases when considering regionalization as opposed to local system operation.
2. The lower the  $R_b$  value, the larger the savings to the region at a specific  $R_a$  value. However, the savings seem not to be highly sensitive to variations in  $R_b$ , until it approaches 50 percent of  $Q_b$ .
3. As  $Q_b$  approaches  $Q_a$ , the potential savings to the region decrease for specific  $R_a$  and  $R_b$  values.

In general, it can be said that when a community A is supplied by a stream whose average flow rate  $Q_a$  is not significantly larger than twice the community's consumption rate  $R_a$ , regionalization with a larger nearby supply system should be considered. Savings in reservoir cost should then be compared to the pipeline and pumping costs added by the regional system.

#### 3.4.3. Supplemental Regionalization

A second hypothetical example involves the case where only partial regionalization of two communities takes place. In this case, it is assumed that the reservoirs on streams a and b are already in existence. It is then learned that community A must increase its required yield by a certain percentage.

Table 3.5 illustrates a comparison of the two alternatives of either raising the capacity of reservoir A or tapping into reservoir B and increasing its capacity. The information pertaining to the existing

systems is the same as that found in Table 3.4 under individual operations.

It is observed from Table 3.5 that, if an increase of 25 percent in the required yield of A is necessary, then to supply the water to meet this demand, either reservoir A could increase its capacity by 92.3 percent or reservoir B could increase its capacity by only 22.9 percent. By becoming partially regionalized, that is, A tapping into B for the required 25 percent increase in sustained yield, a savings of 1.45 million dollars to the system is observed over A increasing its own reservoir.

Similar to the example for complete regionalization,  $R_a$ ,  $R_b$ ,  $Q_a$ ,  $Q_b$ , and the percent increase in  $R_a$  were varied. The result was several similar graphs, one of which is shown here as Figure 3.9. Again,  $R_a$  is plotted against the savings to the region. The sensitivity of the savings to variations in  $R_a$  and  $R_b$  is similar to that shown in Figure 3.8 for Complete Regionalization.

#### 3.4.4. Analytically Optimized Regionalization

It is believed that for both complete and partial regionalization, an analytically optimized regionalization scheme can be found in which the total cost to the entire system would be at a minimum. Therefore, each of the communities involved would be expected to contribute some optimum output to the system. Thus, in relation to the discussion on impounding reservoirs, an optimum reservoir capacity must exist for each community. Hence, the combined reservoir costs can be expressed analytically by using the curves in Figures 3.4 and 3.7.

The curve of Figure 3.7 is a function  $\frac{R}{Q}$  of  $\frac{C}{Q}$  so that if

$\frac{C}{Q} = f\left(\frac{R}{Q}\right)$  then reservoir capacity, C, is derived:

$$(Q)f\left(\frac{R}{Q}\right) = \left(\frac{C}{Q}\right) (Q) = C \quad (3-1)$$

Table 3.5

RESERVOIR COSTS FOR TWO DEMAND CENTERS UNDER  
INDIVIDUAL VERSUS PARTIAL INTEGRATION

		System	
		A	B
Existing	Community		
	Source	a	b
	R, bg/yr	4	10
	Q, bg/yr	10	100
	R/Q	0.4	0.1
	C/Q	1.3	0.07
	C, bg	13	7.0
	Cost, million dollars	4.6	3.2
	Increase in $R_a = 25\%$ Thus, $\Delta R_a = 1.00$ bg/yr		Reservoir Cost Increases
		Res A	Res B
Needed	Expansion at		
	R, bg/yr	5.0	11.0
	R/Q	0.5	0.11
	C/Q	2.5	0.086
	C, bg	25.0	8.6
	% increase in C	92.3	22.9
	Cost, million dollars	6.45	3.6
	% increase in cost	40.2	12.5
Total Cost Increase, million dollars		1.85	0.40
Marginal Savings, million dollars/bg/yr			1.45

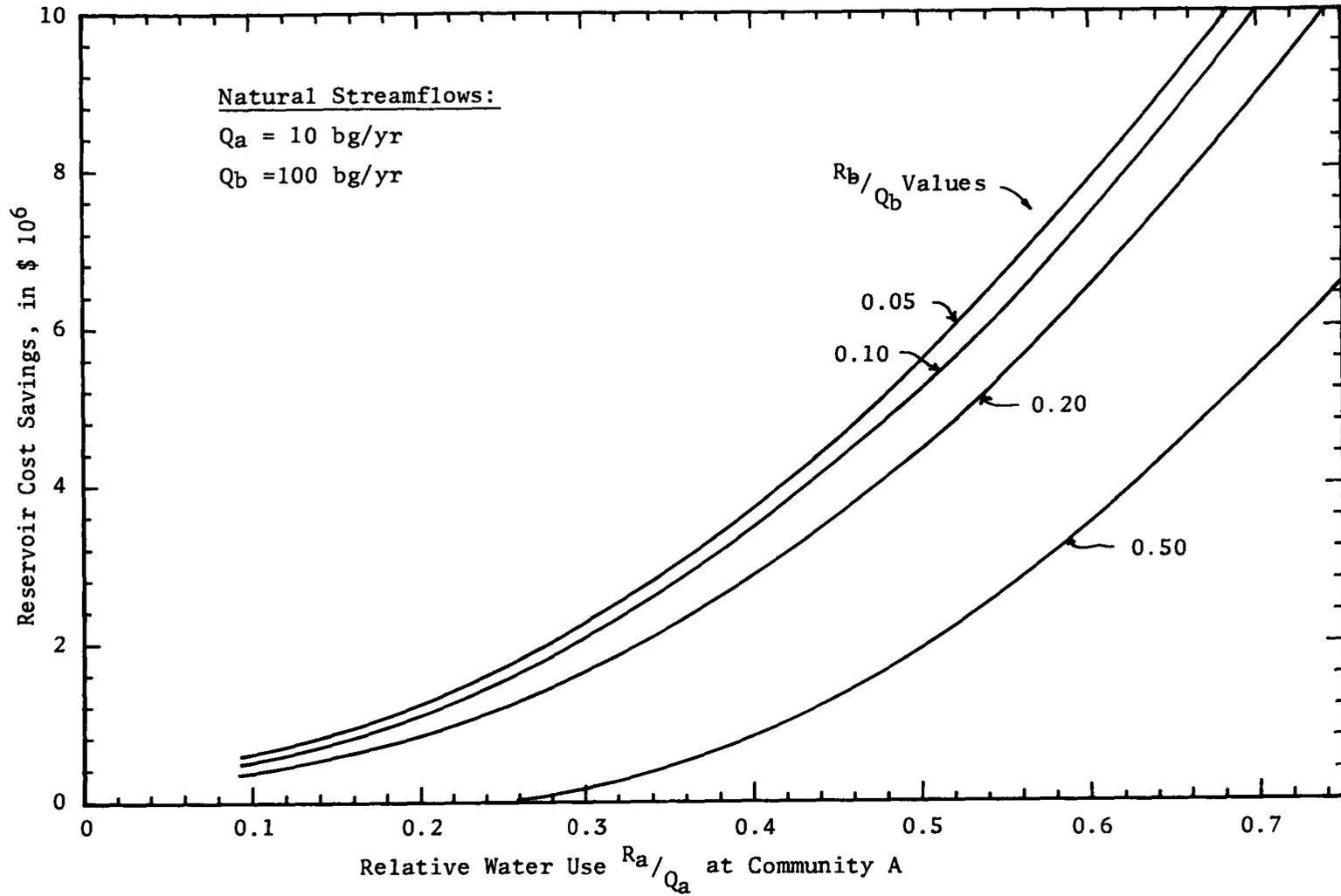


Figure 3.8 - Reservoir Cost Savings under Complete Regionalization

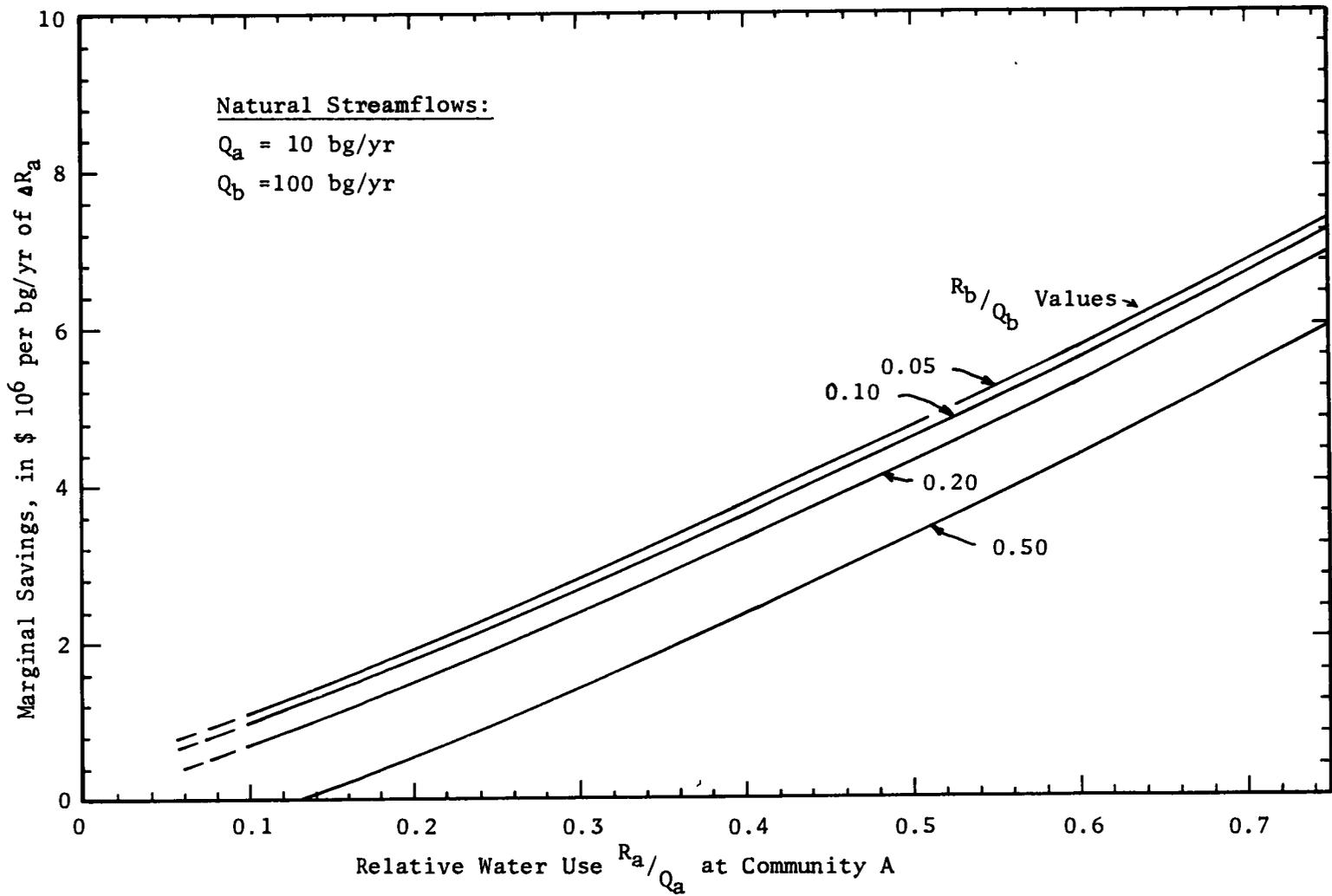


Figure 3.9 - Marginal Reservoir Cost Savings by Supplementing a 25% Increase in Demand at Area A with Flow from Reservoir B

This curve can be approximated by the following equation for  $\frac{R}{Q}$  values ranging from 0.10 through 0.55:

$$\frac{R}{Q} = 0.51 \left(\frac{C}{Q}\right)^{0.27} - 0.15 \quad (3-2)$$

$$C = (Q) \left\{ \frac{\left(\frac{R}{Q}\right) + 0.15}{0.51} \right\}^{3.70} \quad (3-3)$$

The curve in Figure 3.4 is a function of reservoir cost  $C_R$  to capacity  $C$ , namely

$$C_R = g(C) = g \left\{ (Q) f\left(\frac{R}{Q}\right) \right\} \quad (3-4)$$

This curve can be approximated by the following equation for  $C$  values ranging from 0 to 100:

$$C_R = (C)^{0.60} \quad (3-5)$$

Substituting equation (3-3) for  $C$  yields

$$C_R = \left[ (Q) \left\{ \frac{\left(\frac{R}{Q}\right) + 0.15}{0.51} \right\}^{3.70} \right]^{0.60} \quad (3-6)$$

Generalizing,

$$C_R = \sum_{i=1}^n \left[ (Q_i) \left\{ \frac{\left(\frac{R_i}{Q_i}\right) + 0.15}{0.51} \right\}^{3.70} \right]^{0.60} \quad (3-7)$$

where  $n$  is the total number of communities regionalized.

Because the minimum total reservoir cost,  $TC$ , is desired, equation (3-7) must be minimized. This can be done through the application of Lagrangian multipliers. The result is

$$TC = \sum_{i=1}^n [(Q_i) \left\{ \frac{\left( \frac{R_i}{Q_i} + 0.15 \right)}{0.51} \right\}^{3.70} ]^{0.60} + \lambda \left( \sum_{i=1}^n R_i - R \right) \quad (3-8)$$

where  $R = \sum_{i=1}^n R_i =$  maximum required yield of the entire system. Finding the partial derivatives,

$$\frac{\partial TC}{\partial R_i} = 4.35 Q_i^{-0.4} \left\{ \frac{1.96}{Q_i} R_i + 0.294 \right\}^{1.22} + \lambda = 0 \quad (3-9)$$

$$\frac{\partial TC}{\partial \lambda} = \sum_{i=1}^n R_i - R = 0 \quad (3-10)$$

Equations (3-9) and (3-10) are the generalized equations used in determining the analytically optimized  $R_i$  value for community 1.

Using the values from Table 3.4, the following example shows the application of the above equations and the attainment of the optimum values:

$R = 14$  bg/yr = maximum required yield for both communities combined

$Q_a = Q_1 = 10$  bg/yr

$Q_b = Q_2 = 100$  bg/yr

Substituting into equations (3-9) and (3-10),

$$\frac{\partial TC}{\partial R_1} = 1.73 \{0.196 R_1 + 0.294\}^{1.22} + \lambda = 0 \quad (3-11)$$

$$\frac{\partial TC}{\partial R_2} = 0.69 \{0.0196 R_2 + 0.294\}^{1.22} + \lambda = 0 \quad (3-12)$$

$$\frac{\partial TC}{\partial \lambda} = R_1 + R_2 - 14 = 0 \quad (3-13)$$

Solving simultaneously (3-11), (3-12), and (3-13),

$$R_2 = 14 - R_1 \quad (3-14)$$

and

$$1.73 \{3.038 - 0.196 R_2\}^{1.22} - 0.69 \{0.0196 R_2 + 0.294\}^{1.22} = 0 \quad (3-15)$$

which yields

$$R_1 = 0 \text{ bg/yr}$$

$$R_2 = 14 \text{ bg/yr}$$

$$TC = 4.53 \text{ million dollars}$$

This TC is approximately equal to that given in Table 3.4 (TC = 4.85 million dollars). The discrepancy here is probably due to (1) round-off error in the manipulation of the various equations and (2) the approximation of the curves of Figures 3.4 and 3.7 by equations.

This example shows that the optimal case exists where the entire required yield comes from the community II source. Hence, in this case, the idea of complete regionalization is the most economical. The fact that  $R_1 = 0$  in this case brings out the fact that this problem should be subject to the additional inequality constraints  $R_1, R_2 \geq 0$ . This requires use of Kuhn - Tucker conditions under which either  $R_1$  or  $R_2$  are both positive or one of  $R_1$  and  $R_2$  is negative and there is a cost of not permitting expansion of the other system.

#### 3.4.5. Reservoir Cost Savings versus Water Conveyance Costs

The savings in reservoir costs achieved through regionalization should be balanced against pipeline and pumping costs. Through such a comparison the maximum pipeline length can be found over which regionalization remains economically feasible.

The maximum feasible pipe lengths were investigated for the two cases of complete and partial (or supplemental) regionalization as described in sections 3.4.2 and 3.4.3. Pipeline and pump costs were obtained from curves and tables by Black and Veatch (1963), under the assumption of flat land and a friction loss of about 25 ft per mile of pipe length, which was described by Black and Veatch as close to an optimal pipe size. The equations used were the following with R the required pipeflow in billion gallons per year (bg/yr):

Pipe costs (\$ per mile)

$$C_{pi} = 62,000 R^{0.43} \quad (3-16)$$

Pump and pump housing costs (\$)

$$C_{pu} = 180,000 R^{0.90} \quad (3-17)$$

Pumping power costs, based on 25 ft per mile friction loss, 50 percent efficiency and 2 cts per KW hr power costs, converted to present worth (5-5/8 percent interest, 40 yr life) were, in \$ per mile, equal to

$$C_{pp} = 50,000 R \quad (3-18)$$

Figures 3.10 and 3.11 show the results of these cost tradeoff studies. As observed in sections 3.4.2 and 3.4.3, regionalization seems to be a potentially attractively alternative when the smaller community A operates at relative consumption rate  $\frac{R_a}{Q_a}$  approaching or exceeding the value of 0.5, while excess water ( $R_b/Q_b < 0.5$ ) is available at the source of the larger community B.

#### 3.4.6. The Role of Sunk Costs and Regionalization

As alluded to above in several places, sunk costs of investment in

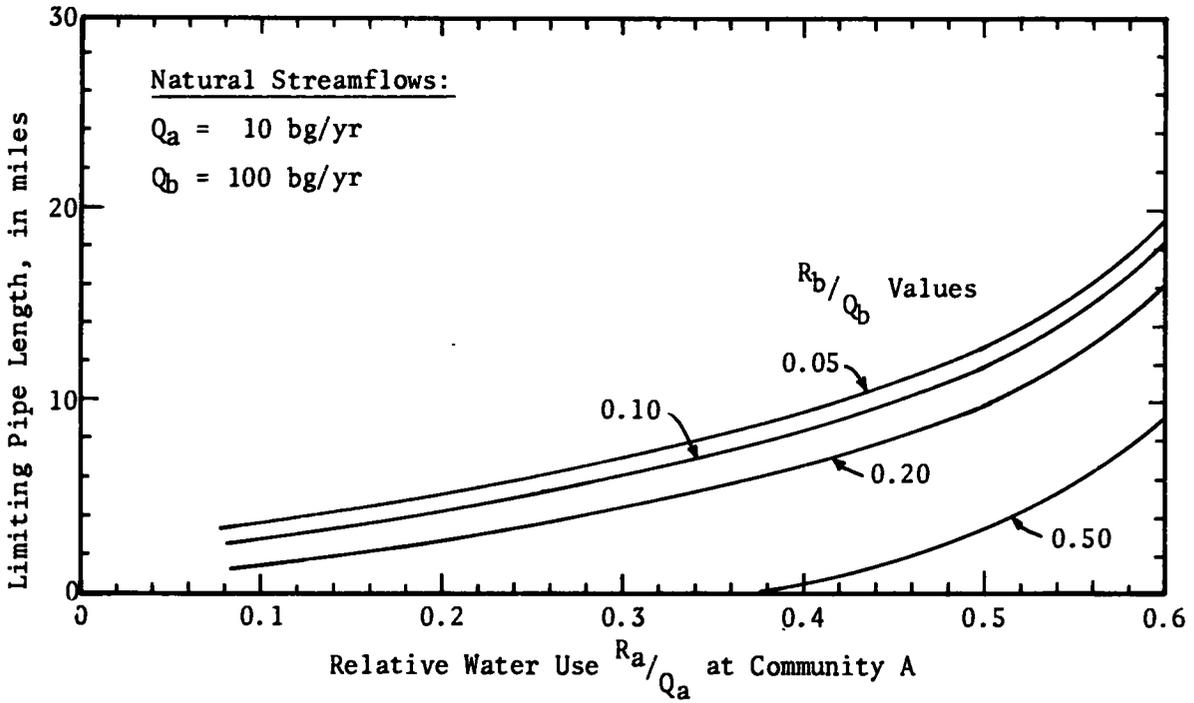


Figure 3.10 - Maximum Economically Feasible Pipeline Length under Complete Regionalization

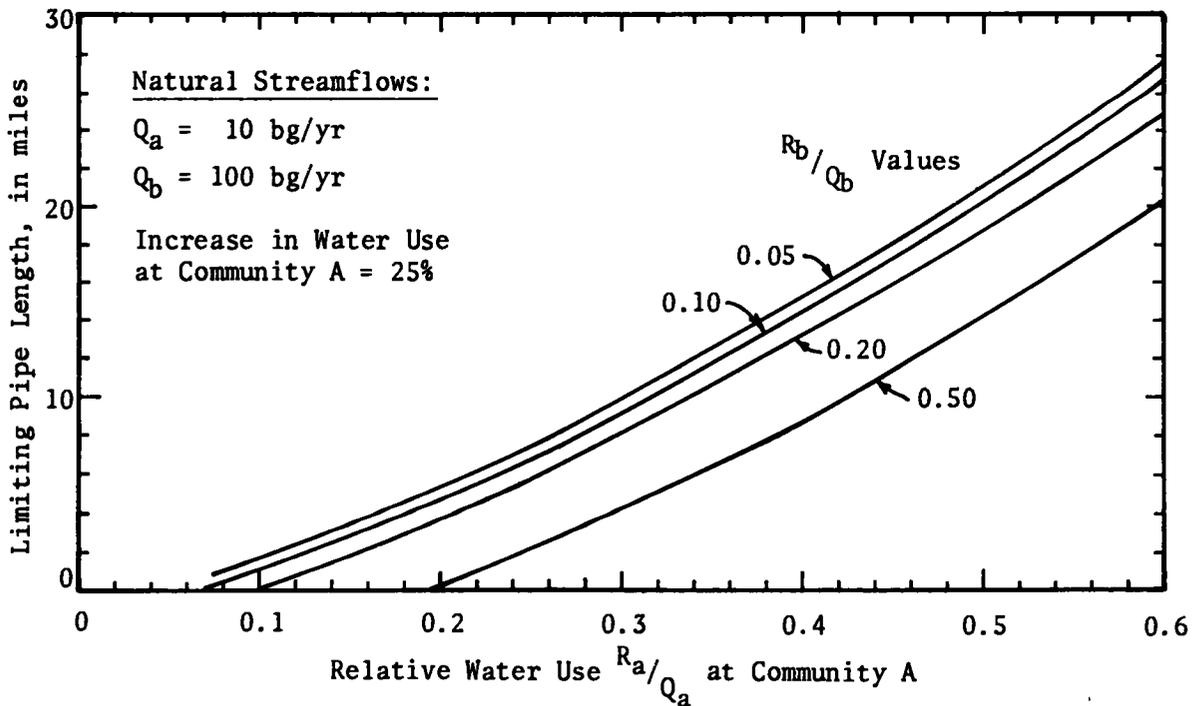


Figure 3.11 - Maximum Economically Feasible Pipeline Length under Supplemental Regionalization

already existing but potential regionalization partners play a crucial role in deciding whether or not regionalization will occur. The techniques used in section 3.4.4 above are similar to those used in the economic model of multiplant monopolists and that is essentially what regionalized partners become. The difference in technique between 3.4.4 and multiplant monopolist models is focused on the difference between operating and fixed costs. In the multiplant monopolist case, the key solution is to set aggregate marginal cost (the horizontal sum of individual plant marginal costs) equal to marginal revenue and allocate backward the optimal outputs required of the individual plants so as to equalize marginal costs among plants. This is all done with regard only to operating (variable) costs. In the model of 3.4.4, the same principle is applied, but it is done with regard only to the essentially fixed costs of the reservoir capacities of each regionalization partner.

The procedures of section 3.4.4 are valid if we are attempting to set up the optimal scale of operations of each partner as we did there, but under the restrictive conditions that no previously existing investments in supply or storage were in place and that operating costs are minor relative to fixed costs. If we now alter our assumptions so as to recognize the plausibility of existing investment prior to planning for regionalization, our planning model would similarly change. The task under the new assumptions is to minimize the sum of new costs, brought about because of regionalization, with recognition given to the fact that already existing capacity is available to the regionalized system free, that is with no opportunity cost. We are under no obligation to utilize existing facilities or if they are utilized to use them to capacity but those decisions will be primarily determined by the

inter-partner operations costs. On account of the latter factor, we introduce operating costs  $O(R_1)$  and  $O(R_2)$  for partners one and two, respectively. We note that existing capacities are given in the two systems as  $\bar{C}_1$  and  $\bar{C}_2$ , respectively. Our problem is to minimize the sum of operating costs, discounted over the planning period  $T$  at rate  $d$ , and capacity costs of expanding beyond current capacities. Notationally, the problem can be written as:

$$\text{Choose } \underset{R_i}{\text{Min}} \text{ TC} = \sum_i \text{Max} \left[ Q_i \left( \frac{\frac{R_i}{Q_i} + .15}{.51} \right)^{3.70} - \bar{C}_i, 0 \right]^{.60} + \sum_i \sum_{j=1}^T O(R_i)(1+d)^{-j}$$

(3-19)

$$\text{ST. } \sum R_i = R \text{ and } R_i \geq 0$$

The importance of the process of equation (3-19) is the observation of changes in consequences as one varies  $\bar{C}_i$ . It is easy to observe, for example, that existing capital structure may have the effect of preventing regionalization in circumstances where that regionalization would have been beneficial and warranted had only there existed no previous sunk investment. This would occur in the following situation. Assume that regionalization would produce cheaper operating costs by equating partners' marginal operating costs, but require capacity adjustment in order to obtain the operating cost savings. Even if the altered capacities cost the same as the existing capacities if both were to be newly constructed, regionalization might still not be warranted. Specifically, it would not be warranted when altering the capacity (increasing it) of one or more potential partners, causes enough new construction costs to overbalance the savings on operations.

Variation of  $\bar{C}_1$  in (3-19) also can prevent optimal regionalization, that is, equation of partners' marginal costs, even when regionalization is justified. We are likely to find partners, even after they have successfully regionalized, failing to equalize long run marginal costs because of the previous capital investment and reluctance to make new capital investment while old capacity is made idle. The result in this case is likely to be some capacity adjustment but not all that would occur in the absence of previous sunk investments. The result will lead to equating of the marginal costs relevant to the chosen capacities, i.e., short run marginal costs, but this is not the same as equating long run marginal costs. The difficulty of the result, of course, would be lessened if reservoir capacity had shorter life expectancies, or if the population was more mobile and variable over time. These conditions, however, do not occur with the result that the beneficiality of regionalization is reduced and is more often insufficient to entice communities away from the status quo and into regionalization.

#### 3.4.7. Conclusions in Regard to Reservoir Integration

The previous examples have demonstrated that under favorable conditions, the regionalization of two water supply systems through combination of their impoundment reservoirs may yield sufficient savings to offset the costs of connecting pipelines. However, the examples were based on the Black and Veatch curve for reservoir requirements to sustain a given required safe yield.

In northeastern U.S. watersheds, streamflow is relatively stable and reservoir requirements may be lower, thus reducing the savings through regionalization.

Costs and savings computed in this chapter should be considered highly generalized and relative because the Black and Veatch curves were intended for rough cost comparisons rather than rigorous contractor's cost estimates.

In Chapter IV the feasibility of regionalization will be geared more specifically to Northeast United States stream conditions. Costs will be escalated to 1974 price indices and the costs or penalties for water supply shortages will be evaluated.

## CHAPTER IV

### THE THREAT OF WATER SHORTAGES AS INCENTIVE FOR REGIONALIZATION OR RESERVOIR ENLARGEMENT

During the microscale phase of the study it was established that regionalization of water supply systems is not only socially unpopular but in many cases more expensive than the development or expansion of individual systems. Three factors were cited as swinging the balance in favor of regionalization:

- a. The need for a sophisticated water treatment plant
- b. The need for major storage reservoirs
- c. The threat of severe water shortages

The effects of reservoir requirements and specialized water treatment were given consideration in Chapter III.

#### 4.1 Water Shortage Loss Functions

The threat of water shortages was recognized from the very beginning of the study as a strong potential factor to encourage water supply regionalization. The lack of well documented data of water shortage costs has hampered the efforts of a rigorous analytical treatment of the problem. Water Resources Engineers (Young et al., 1972) studied the effects of the 1964-66 drought on several industries in York, Pa., but their report only cites some individual economic loss estimates without relating these to the percent water shortage or even the total water demand of the particular industries.

Russell, Arey and Kates (1970) presented drought damage figures for these communities. These authors made a considerable effort separating losses actually due to water shortages from costs due to emergency

augmentation of water supplies. They also pointed out the difference between the shortage losses as seen by a local community in which an important industry may move, leaving a large void in the local economy, and losses as seen from a national level, with industrial mobility assumed and where a new industrial location would benefit from the move. Some municipalities did not report any losses because a flat rate for water services was charged, yet the drought must have had some unfavorable impacts, at least in the form of annoyances and inconveniences. Figure 4.1 illustrates a few strongly varying relationships between expected per capita losses and the inadequacy ratio  $\alpha = \frac{D}{Y}$  in which D and Y are the demand and safe yield of a community supply. It can be seen from the figure that loss estimates can vary widely depending on the model and assumptions used. In our studies the losses from the empirical model, from the local point of view and with a 20 percent discount rate were used for a comparison with losses developed from the Hufschmidt-Fiering (1966) curves.

Hufschmidt and Fiering summarized reported losses from Lehigh, Pa., in Figure 4.2. No breakdown of these losses is given in their work, and it is impossible to judge how widely applicable these shortage costs are. The Hufschmidt-Fiering loss function was converted by Stottmann (Aron et al., 1974) to a monthly shortage index

$$SI_i = \left( \frac{2 Sh_i}{R_i} \right)^{1.63} \quad (4-1)$$

in which  $R_i$  and  $Sh_i$  are the water demand and shortage during a month  $i$ , respectively. The equation is represented by the single curve in Figure 4.2. An average annual shortage index can be obtained by adding all monthly shortage indices found over a period of investigation and dividing the sum by the number of years.

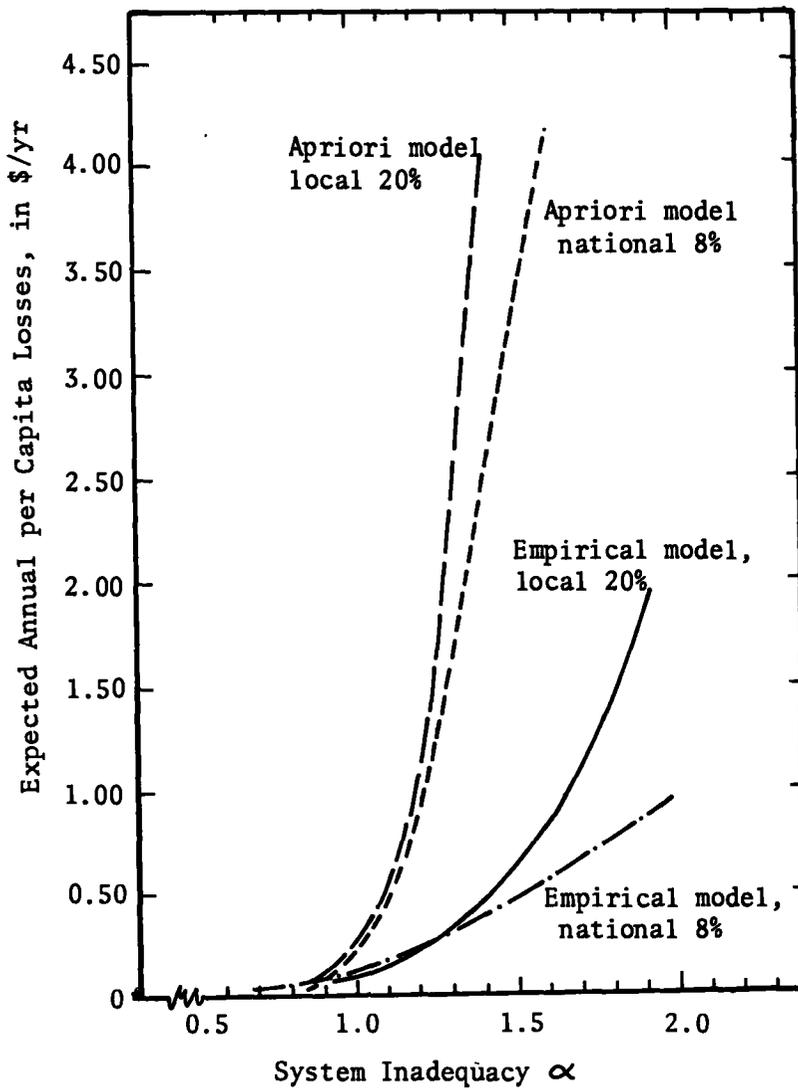


Figure 4.1 - Water Loss Functions (after Russell)

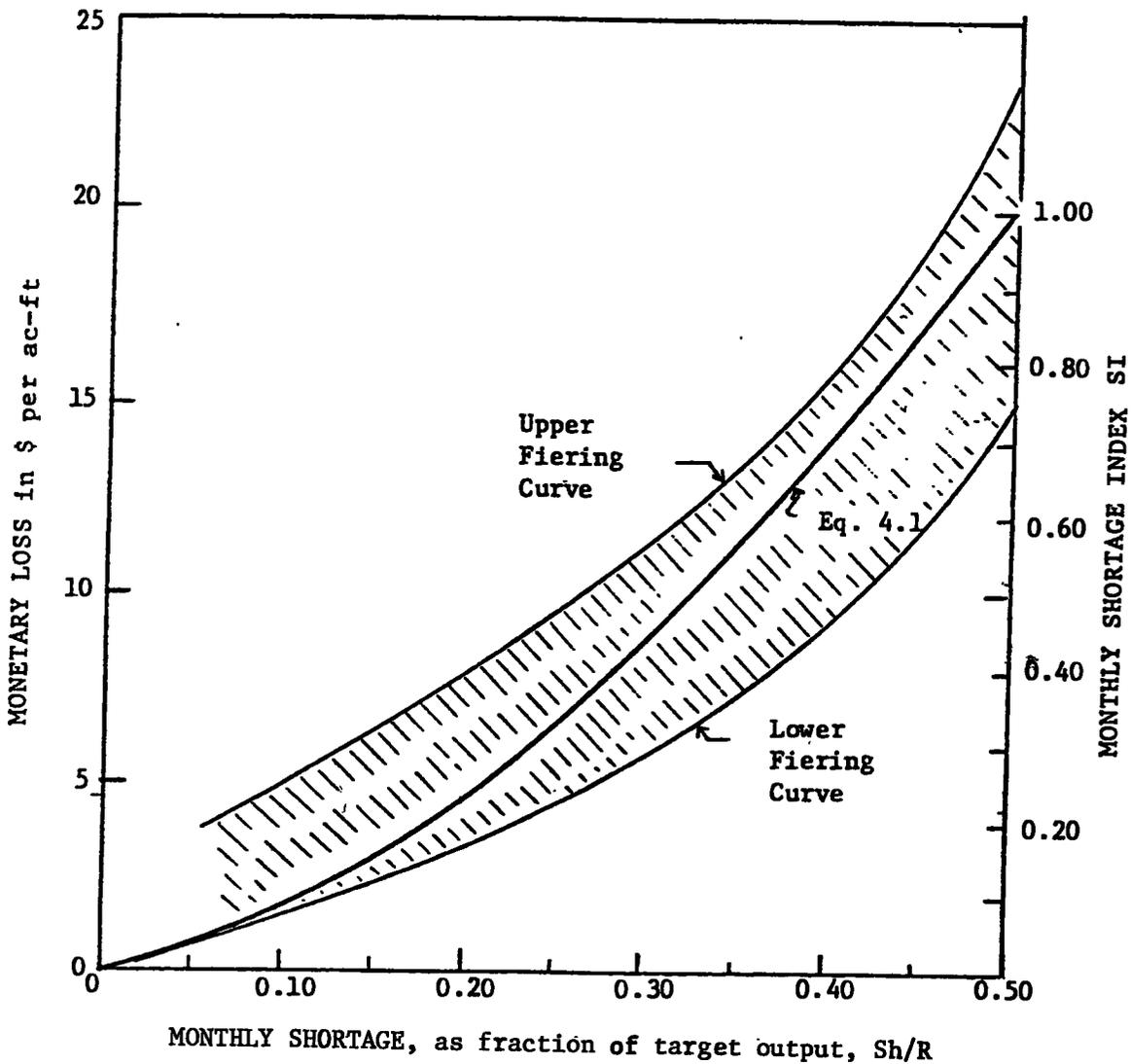


Fig. 4.2 - Water Supply Loss Function for Lehigh, Pa., and Corresponding Monthly Shortage Index (after Hufschmidt-Fiering)

From Figure 4.2 the shortage loss, in U.S. Dollars, can be expressed as

$$SL = 20 \cdot SI \cdot Sh \quad (4-2)$$

if the shortage  $Sh$  is expressed in ac-ft.

To apply the shortage index concept and shortage loss function usefully, the following transformations and analyses were needed.

1. Transform the loss function into a form in which losses are a function of shortage index  $SI$  and requirement  $R$  instead of shortage  $Sh$ .
2. Analyze the firm yield of a number of typical North Atlantic Region streams to determine the relationship between relative firm yield  $R/Q$  without shortages as a function of  $C/Q$  (the ratio of reservoir capacity to average annual stream flow volume), as well as the functionality between shortage index  $SI$  and any combination of  $R/Q$  and  $C/Q$ .
3. Combine the findings in steps 1 and 2 to produce cost curves which reflect the effects of water shortages on water system costs.

#### 4.2 Transformation of the Shortage Loss Function

Equations (4-1) and (4-2) can be combined to produce the transformed equation

$$\begin{aligned} SL &= \frac{20}{2} SI \frac{2 \cdot Sh}{R} R = \\ &= 10 SI^{1.60} R \end{aligned} \quad (4-3)$$

for R expressed in ac-ft, or

$$30.7 SI^{1.60} R \quad (4-4)$$

when R is expressed in mg (million gallons)

#### 4.3 Firm Yield Analysis

Whereas for the preliminary micro-scale study the Black and Veatch curve for storage-yield relationships (Figure 3.7) was considered sufficiently representative to describe conditions under which water system regionalization would become economically feasible, it was decided at this point to determine storage yield relationships more specifically for Northeastern United States streams, which tend to flow with much more regularity than some mid West streams which may have formed the basis for the Black and Veatch curve.

The stream flows at the Northeast Susquehanna River Basin gages listed in Table 4.1 were analyzed for firm yield and shortage index. The period of analysis was 1950 to 1974, only 25 years, but these years included the 1964-65 drought period, which has been recognized by the Corp's North Atlantic Water Supply study as a possible 50 to 100 year drought. Thus, any firm yield or shortage index determined from these data should be on rather conservative and safe ground. A synthetic stream flow generation of many years could have been determined, but it was felt that such a series would mostly have reflected the trend of flows of the 25-year sample.

Table 4.1

NORTHEAST SUSQUEHANNA DRAINAGE BASINS USED IN THE  
FIRM YIELD AND SHORTAGE INDEX STUDIES

USGS Gage No.	Gage Name	Drainage Basin Area, sq. mi.
1-4975	Susquehanna River at Colliersville, NY	351
1-4990	Otego Creek near Onconto, NY	108
1-5000	Ouleout Creek at East Sidney, NY	103
1-5005	Susquehanna River at Unadilla, NY	982
1-5015	Sage Brook near So. New Berlin, NY	0.7
1-5020	Butternut Creek at Morris, NY	60
1-5050	Chenango River at Sherburne, NY	263
1-5055	Canasawacta Creek near So. Plymouth, NY	58
1-5070	Chenango River at Green, NY	593
1-5080	Shackham Brook near Traxton, NY	3.1
1-5105	Otselic River near Upper Lisle, NY	217

In the firm yield analysis, the dimensionless notation used by Black and Veatch was adapted, except that the notation for firm yield was changed from R to Y, because the symbol R was to be left to denote requirement which may not always be fully met if the alternative of accepting a shortage is considered. For each of the 25-year streamflow sequences of the 11 streams selected, yield requirements varying between 15 and 50 percent of the long term average streamflow were applied to the recorded historic flows on a month-to-month basis, and the required reservoir storage to satisfy these required yields were determined and plotted in

Figure 4.3. The best-fitting line through these points fits the equation

$$\frac{Y}{Q} = 1.32 \left( \frac{C}{Q} \right)^{0.733} \quad (4-5)$$

which should be applicable to the range

$$0.15 \leq \frac{Y}{Q} \leq 0.50$$

or possibly slightly beyond.

In comparison to the Black and Veatch curve it seems that streams in the humid Eastern U.S. require much less storage for a given firm yield than those streams analyzed by Black and Veatch.

#### 4.4 Shortage Index a Function of R/Q and C/Q

An extension of the firm yield study was the investigation of shortages expected when the relative storage capacity C/Q is smaller than the C/Q needed to fulfill a requirement R/Q. The shortage index, explained above was computed and plotted in Figure 4.4 as a function of R/Q and C/Q.

For later analytic treatment the shortage, a general shortage index function was derived, namely

$$SI = \alpha \left( \frac{R}{Q} - \beta \right)^\gamma \quad (4-6)$$

in which the parameters

$$\alpha = 10^{(1.8 - 3.5 C/Q)}$$

$$\beta = 0.0075 + 1.25 C/Q$$

$$\gamma = 3.42 (C/Q)^{0.15}$$

Thus the shortage index was expressed entirely as a function of R/Q and C/Q. It could be argued that the parameter  $\beta$  should be equal to

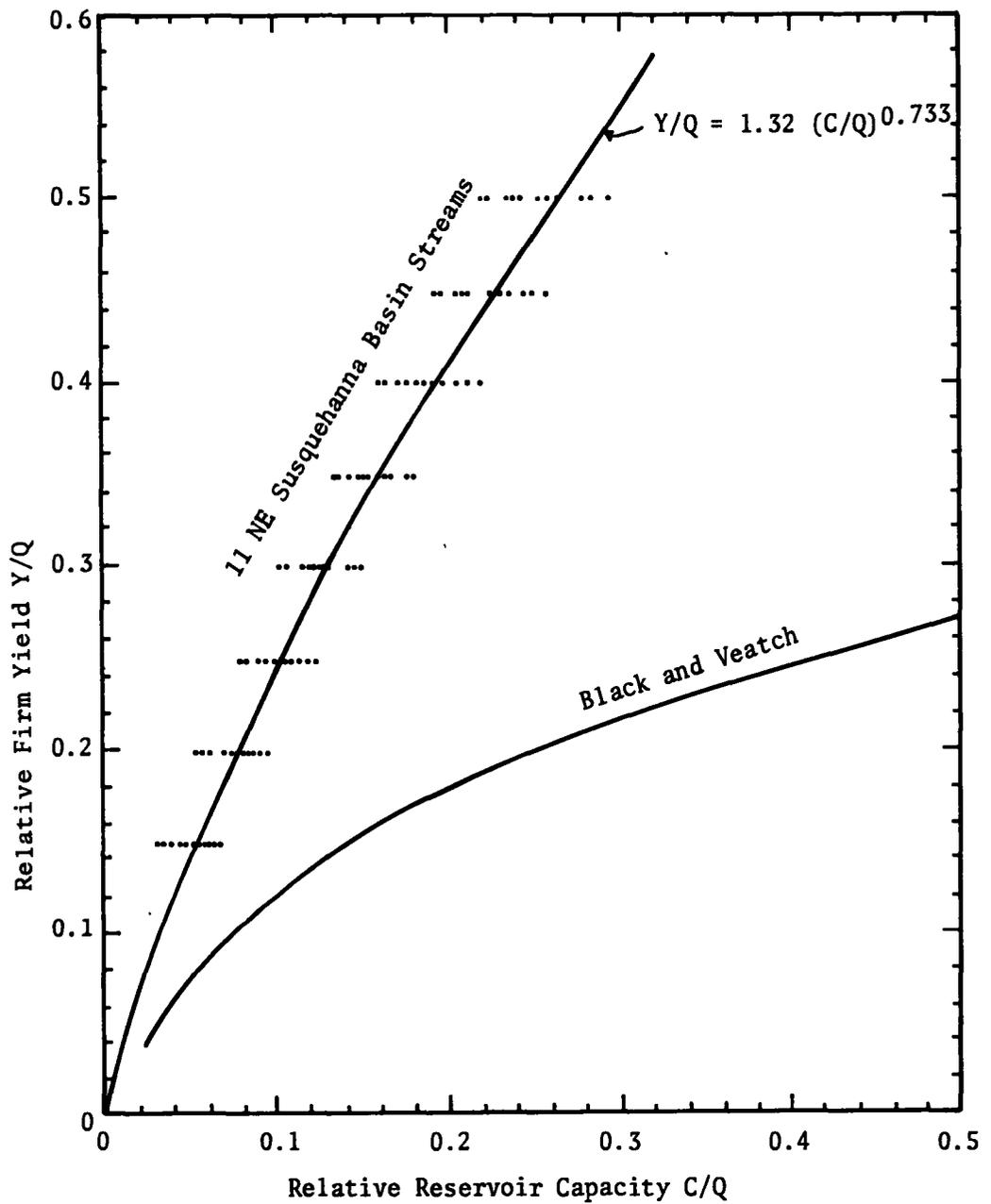


Figure 4.3 - Relationship of Firm yield to Reservoir Storage Capacity

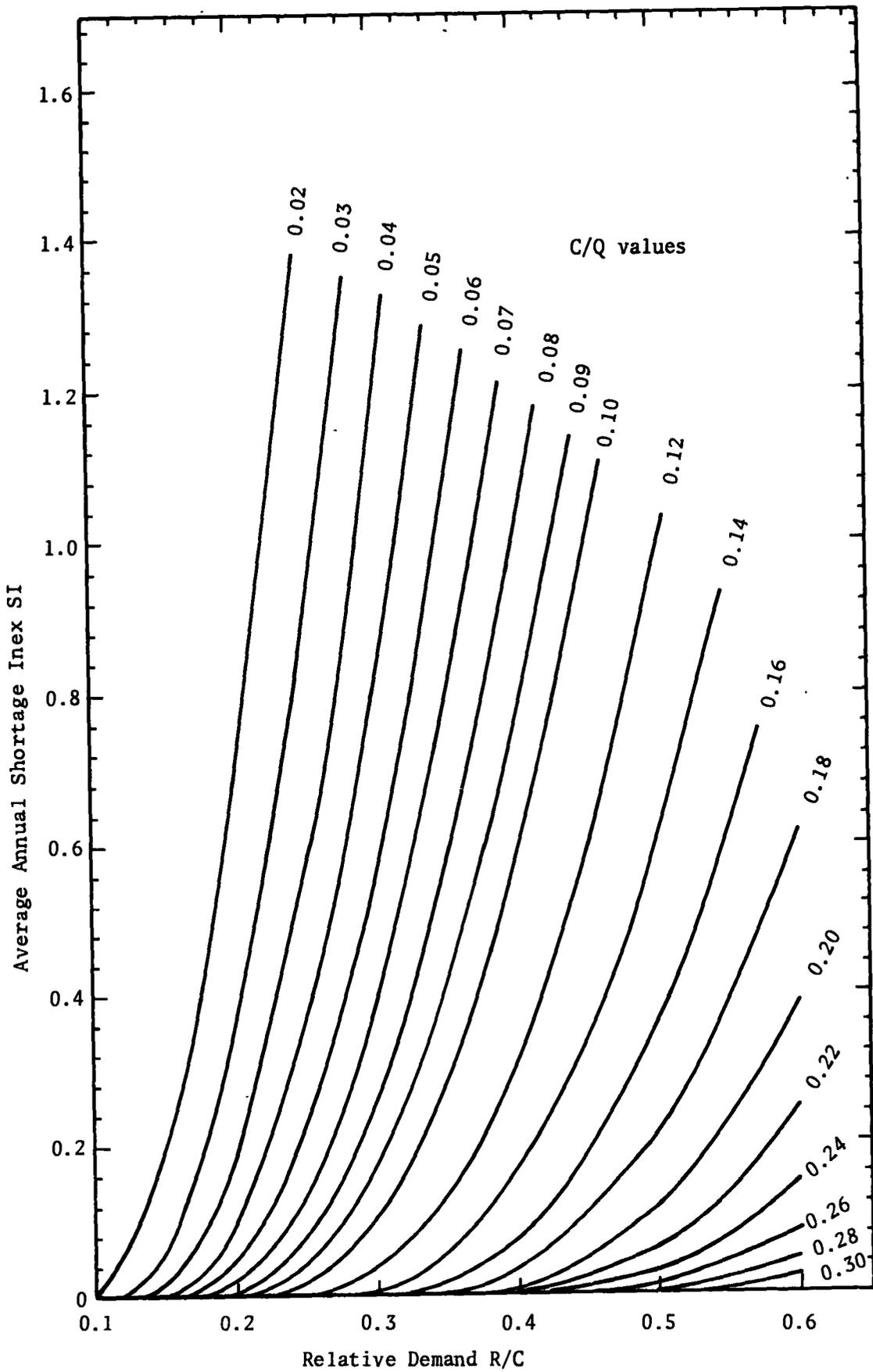


Figure 4.4 - Shortage Index as a Function of  $R/Q$  and  $C/Q$

the relative firm yield  $Y/Q$  from Equation 4-5, determined earlier, to make the shortage index converge to zero whenever  $R/Q$  approaches  $Y/Q$  but it should be noted that Equation 4-5 was derived from a best fitting equation like in Figure 4.3, which left the possibilities of some shortages in a few of the streams.

#### 4.5 Tradeoff Between Reservoir Costs and Shortage Losses

Because it was realized that small occasional water shortages cause only small damages or financial losses to communities, it seemed worthwhile to examine the tradeoff between savings due to reduced reservoir costs and expected shortage losses.

Black and Veatch presented a reservoir cost curve following the equation

$$C_r = C^{0.6} \quad (4-7)$$

in which the reservoir cost  $C_r$  is expressed in  $\$ 10^6$  and  $C$  in  $\text{bg}$  ( $10^9$  gal). In Figure 4.5, the Black and Veatch curve is plotted next to cost data provided by Russell et al., and the agreement was found to be surprisingly good. The Black and Veatch cost equation, already used in the micro-phase study, was used in this study phase likewise, but costs were inflated by a factor of 2.2 as an adjustment to construction costs between 1962 and 1974. The update reservoir cost equation is then

$$C_r = 2.2 C^{0.6} \quad (4-8)$$

The Lehigh shortage costs compiled by Hufschmidt and Fiering date back to sometime between 1960 and 1965, therefore the same inflation factor of 2.2 was applied to shortage losses.

To express the expected annual shortage losses in terms of present

worth, the present worth factor of 15.79 for a 5-5/8 percent interest rate with a 40 year amortization time was used. Thus, the water shortage cost Equation 4-4 is modified to:

$$\begin{aligned} C_{Sh} &= 30.7 \times 2.2 \times 15.79 SI^{1.60} R & (4-9) \\ &= 1065 SI^{1.63} R \end{aligned}$$

for  $C_{Sh}$  in \$, R in mg/yr, or

$$C_{Sh} = 1.065 SI^{1.63} R \quad (4-10)$$

when  $C_{Sh}$  is expressed in \$  $10^6$  and R in bg/yr

The tradeoff cost comparison could not be kept completely dimensionless because it is dependent on the scale of development. Tradeoff computations were run for Q varying between 0.5 and 8.0 bg per year, and over ranges

$$0.2 \leq \frac{R}{Q} \leq 0.7$$

and  $0.01 \leq \frac{C}{Q} \leq 0.4$

Figures 4.5 and 4.7 illustrate the combined present worth of costs of water shortage and reservoir cost. The curves show that for undersized reservoirs the shortage index, and thus the shortage costs, rise very quickly, whereas reservoir costs show only a gradual rise.

The shortage index was also plotted into the cost comparison curves and confirms statements made by Stottmann (Aron et al., 1974) that a shortage index approaching unity results in exorbitant shortage penalties. It seems from Figures 4.6 and 4.7 that a shortage index of roughly 0.2 tends to result in minimum total costs. However, unless the water manager

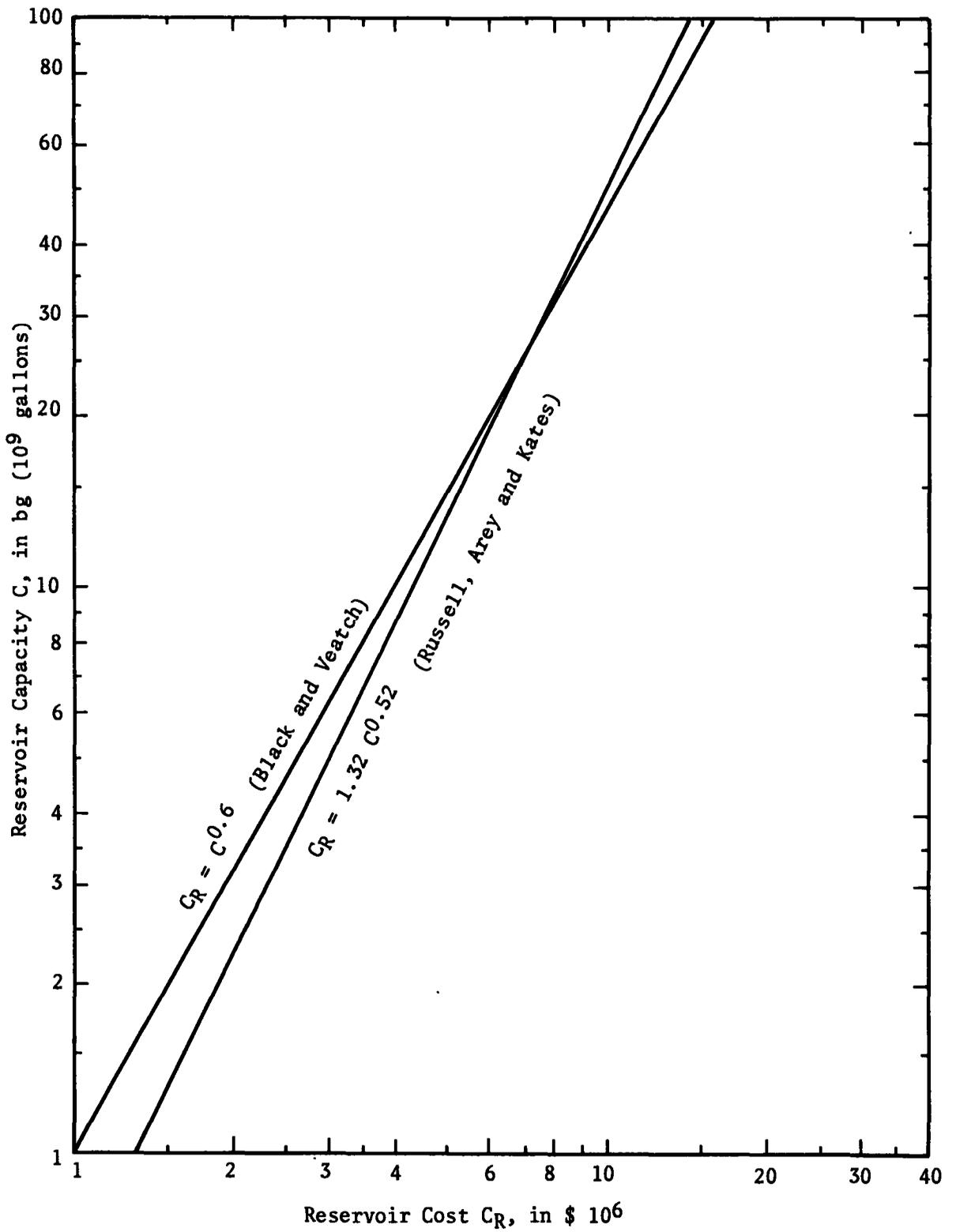


Figure 4.5 - Reservoir Construction Cost Curves

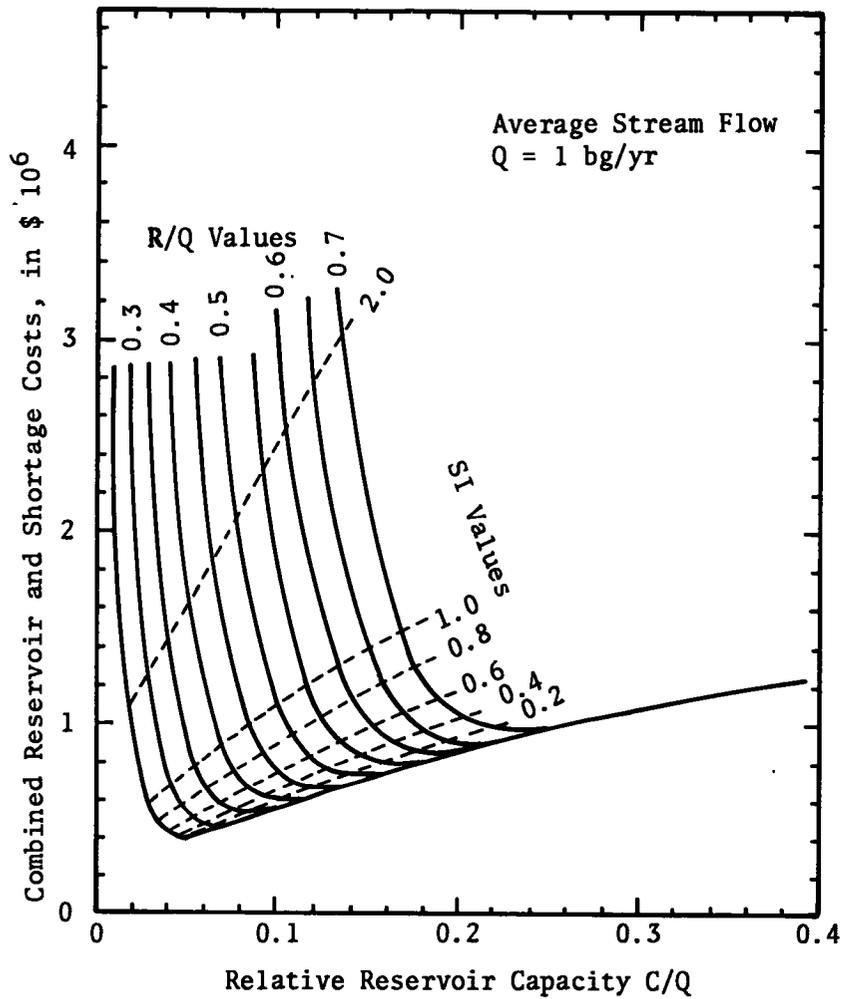


Figure 4.6 - Tradeoff between Reservoir Costs and Shortage Losses ( $Q = 1 \text{ bg/yr}$ )

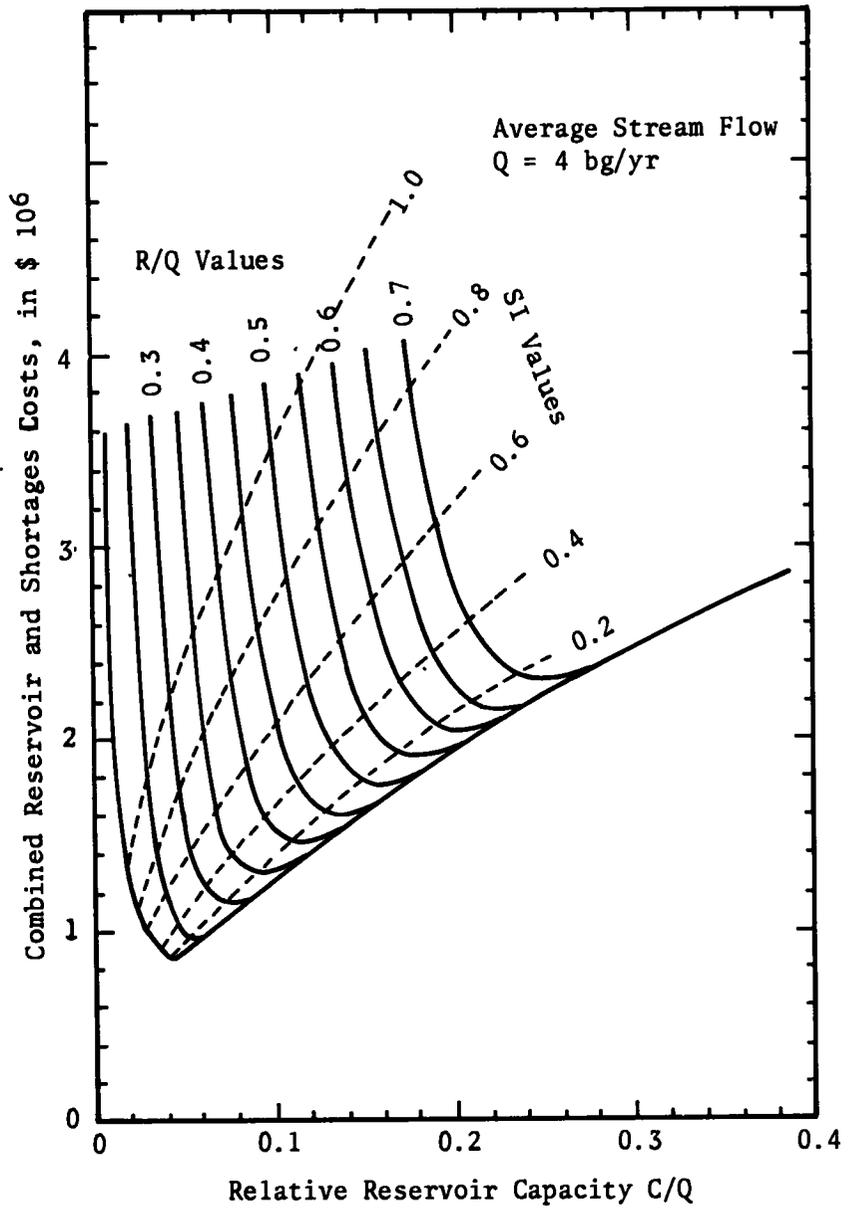


Figure 4.7 - Tradeoff between Reservoir Costs and Shortage Losses ( $Q= 4\text{bg/yr}$ )

is very sure of his control of water releases and yields, it seems risky to play the brinkmanship of planning for occasional shortages. An unforeseen water loss from the reservoir coupled with a severe drought and rising water demands, could precipitate the system quickly into a situation of economically disastrous water shortage. If reservoir space is indeed so scarce, it would seem preferable to look into the possibility of backup ground water systems operated under the "preventive pumping role" advocated by Stottman (Aron et al., 1974).

#### 4.6 Comparison of Shortage Costs Obtained from Hufschmidt-Fiering and Russell Curves

As one further shortage cost analysis, the shortage losses reported by Russell et al., (1970), previously shown in Figure 4.1, were adapted from per capita losses to losses as a function of R/Q and C/Q ratios. The origin of the loss data was considerably different, and Russell's data in themselves show a wide variation between the "a priori" and "empirical" curves. The empirical curves, which seem to have been constructed from data adjusted for double accounting and other questionable damage claims, was chosen as more applicable, and local damages rather than rational ones (in which costs by one community are offset by gains at another community), were chosen.

Russell's empirical cost curve for local damages at 20% discount factor obeys the equation

$$C_{Sh} = 0.1 \alpha^{4.8} \quad (4-11)$$

in which  $\alpha$ , the "inadequacy index," is equal to the ratio between our analysis' relative demand R/Q and the relative firm yield Y/Q, which had been investigated using data from 11 Susquehanna Basin streams.

Making the assumption that per capita water use is roughly 50,000

gal per year, and using the Susquehanna Basin firm yield relationships a set of relative shortage cost curves was generated from both Hufschmidt's and Russell's cost data. These costs expressed in \$ per bg/yr of stream flow and as a function of R/Q and C/Q are illustrated in Figure 4.8. It will be noted that the costs agree quite well as the shortages become severe, but that Russell's costs for small shortages are much higher than Hufschmidt's. This is largely due to the peculiarity in Russell's equation which shows shortage costs even when the inadequacy index is unity, at which point there should be no shortage. Overall, however, considering the difficulty and ambiguity in even defining costs due to water shortage, the agreement was good enough to continue the use of the Hufschmidt loss function.

#### 4.7 Inclusion of Shortage Costs in a Two-Source Regional Supply System

As a continuation of the supplemental regionalization example, presented in Section 3.4.3, of a system established with a small reservoir which could choose to either stay with their present system, import part of their needs from a neighboring, larger system, or join the larger regional system outright, the shortage losses evaluated in the previous sections were included in the regionalization alternatives.

To consider the effects of possible shortages, the average streamflows  $Q_1$  and  $Q_2$  at the small local and the larger regional source were fixed at 10 and 50 bg/yr (42 and 210 cfs, respectively). The demands were fixed at  $D_1 = 5$  bg/yr and  $D_2 = 15$  bg/yr and the storage capacity in the local system was fixed at 1.0 bg in Figure 4.9 and 1.5 bg in Figure 4.10. Left as variables were the conveyance distance  $L$  and the topographic rise  $\Delta Z$  from the regional source to the local demand center, and finally the supply requirement  $R_1$  to be imposed on the local system is left as the

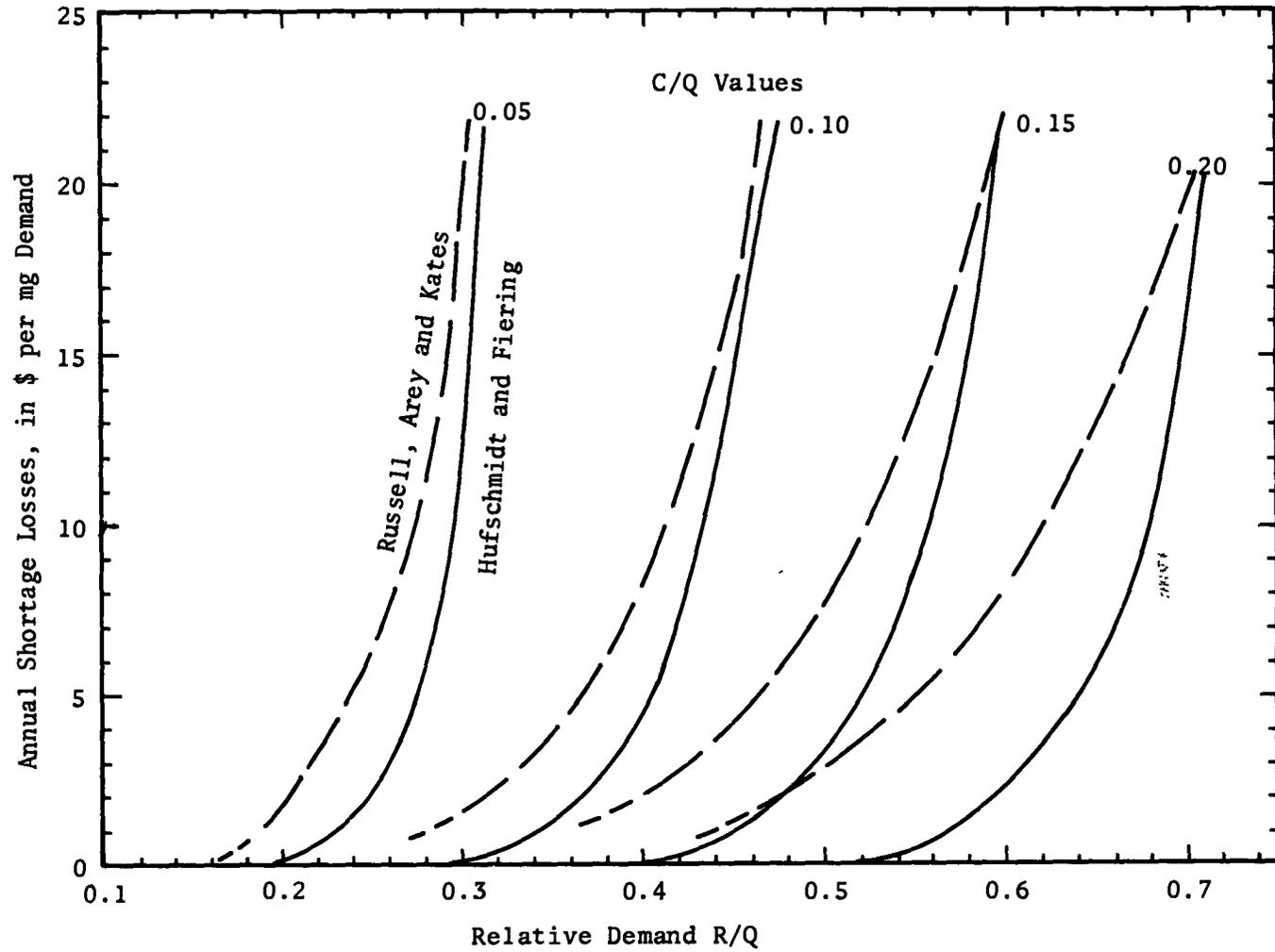


Figure 4.8 - Comparison of Shortage Loss Functions

decision variable to be optimized. The difference  $D_1 - R_1$  would be imported from the regional system.

The shortage costs from the Hufschmidt curves follow the equation

$$C_{Sh} = k \times SI^{1.60} R_1 \quad (4-12)$$

in which  $k$  is a cost factor defined in Section 4.4 as 30.7, to be multiplied by a factor of 2.2 to account for inflation between 1963 and 1974. Since these costs were taken from a rather broad band of data, cost factors  $k$  of 50 and 100 instead of  $30.7 \times 2.2$  were used to show the sensitivity of total costs to doubling the shortage penalty.

The annual system costs in Figures 4.9 and 4.10 include the reservoir expansion in the regional system, pipeline and pumping costs for water conveyance, pump house installation and maintenance, and naturally shortage losses in the local system.

Due to the many variables ( $D$ ,  $Q$ ,  $R$ ,  $L$  and  $\Delta Z$ ) involved in a problem of this nature, it was not possible to generate general design curves. The curves in Figures 4.9 and 4.10 are specific to the combination of variables cited, however they do show the rather pronounced effects of the shortage cost factor  $k$  as well as the storage capacity  $C_1$  (available at the local source) on the optimal decision  $R_1$ . Increasing pipe length  $L$  and elevation difference  $\Delta Z$  would considerably boost total costs but not appreciably shift the magnitude of the least-cost value of  $R_1$ .

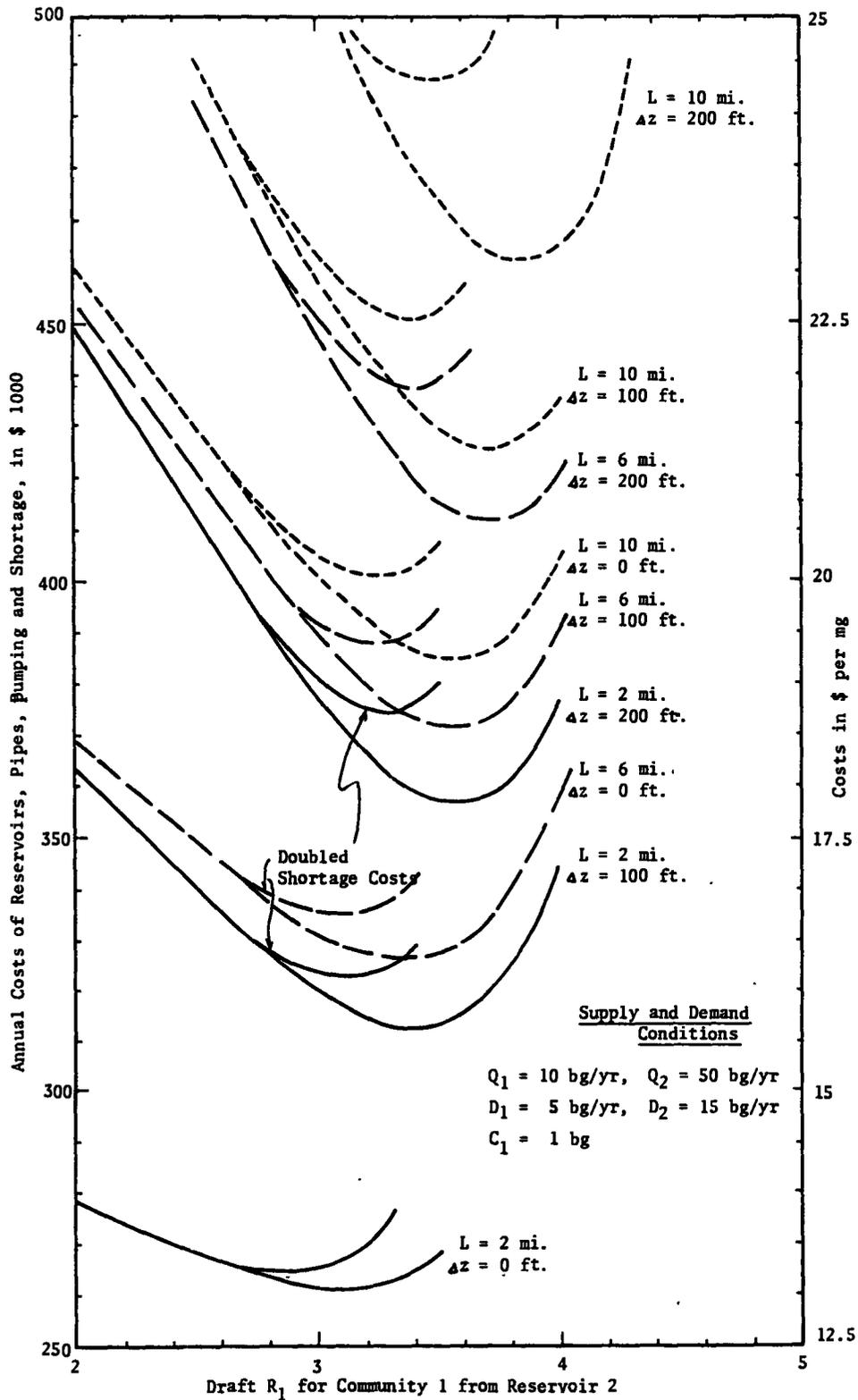


Figure 4.9 - Effects of Shortage, Pipe Length and Gradient On Water System Costs ( $C_1 = 1 \text{ bg}$ )

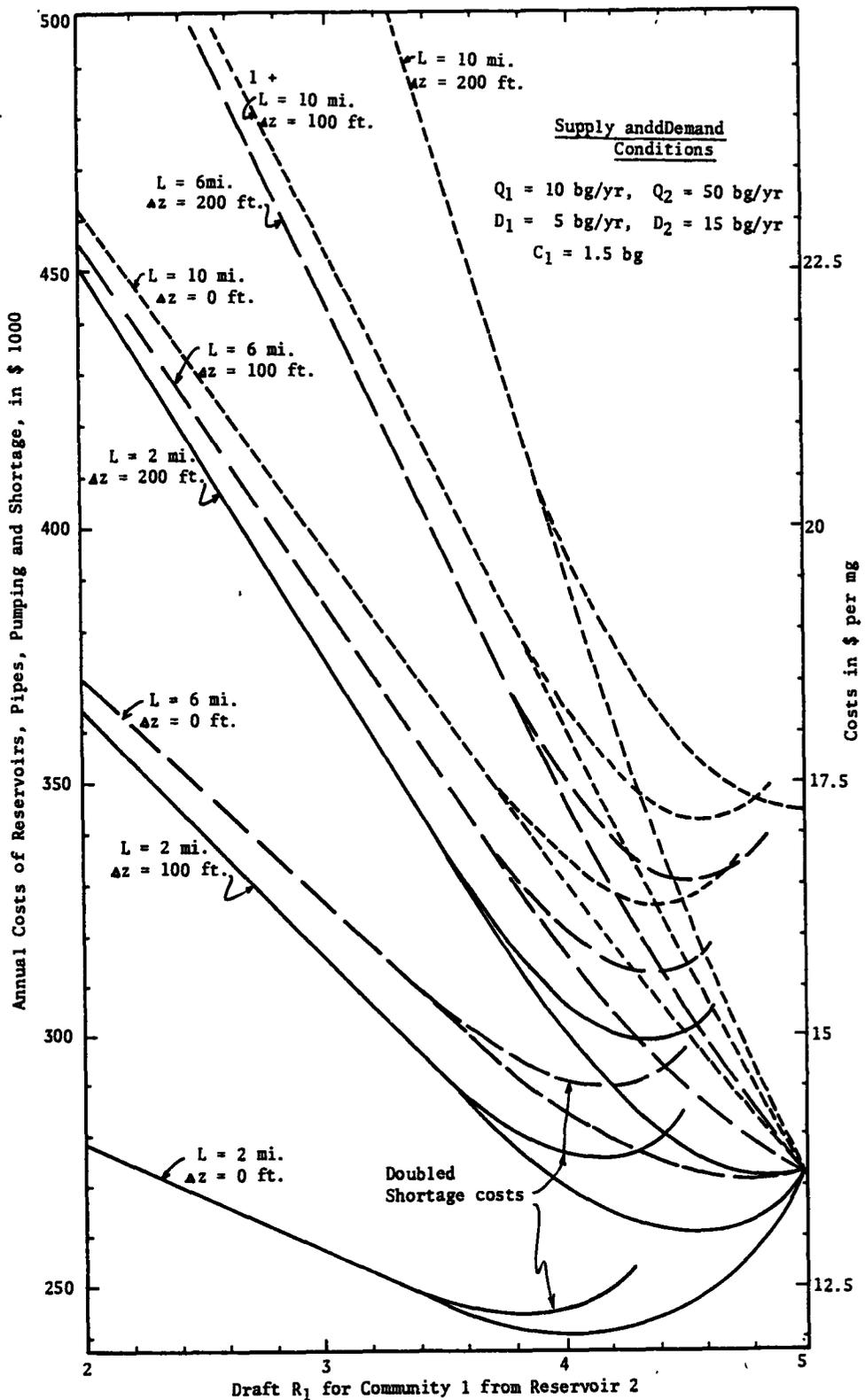


Figure 4.10 - Effects of Shortage, Pipe Length and Gradient on Water System Costs ( $C_1 = 1.5 \text{ bg}$ )

#### 4.8. An Economic Interpretation of Shortage Losses

The methods used in sections of 4.1 and 4.2 of this report as well as their antecedents, Young et al. (1972) and Huffs Schmidt and Fiering (1966), appear to deviate from the traditional economic perspective. In fact, they do not, but they do make implicit assumptions about the economic world. If these are laid bare, an interpretation of sections 4.1 and 4.2 is more accessible to all, allowing us to capitalize not only on the few specific instances of case studies of water shortage, but also on the broader literature of water demand analysis, including all the studies summarized in ChioGioji and ChioGioji (1973), Grima (1972) and Hogarty and Mackey (forthcoming).

The use of any economic commodity is evaluated from a welfare perspective as the integral over quantity consumed of net willingnesses-to-pay (price paid plus consumers' surplus) minus marginal costs. Notationally,

$$\int_{q=0}^{q_E} [p(q) - mc(q)] dq \quad (4-13)$$

where  $p(q)$  is the demand function,  $mc(q)$  is the marginal cost function, and  $q_E$  is the equilibrium consumption. This model ignores externalities and divergences of private from social costs and benefits, but it is the model that generates the famous marginal cost pricing doctrine of efficiency. Even if marginal cost pricing is not used in the water market, so that  $q_E$  is cut off by some other price, this evaluative method, (4-13) is still valid and can be used to estimate the value of water shortages so long as rationing during water shortages is done by a technique which approximates a pricing

solution. Namely, if rationing occurs cutting off the lowest marginal uses so that the solution can be characterized by inter-consumer equality of marginal benefits from water, then the integral method works.

The above arguments cause specific practical objections to using the integration method in evaluating water shortages. The first is the problems presented in working with an aggregate demand function,  $p(q)$  when individuals are typically charged by a municipal pricing schedule (downward step-block pricing). This presents problems not only in defining an aggregate demand function because of the lack of a common aggregate price definition, but also in voiding the assumption that the marginal benefits of consumers' water use are equalized even initially before the shortage. The second objection to the integration method of evaluating water shortages is the typical fact that when shortages occur, there is a differential policy for each of residential, commercial and industrial users. This can hardly promote equality of marginal benefit of use of the last units rationed to each consumer. In fact, however, even if consumers were treated equally to equal cutbacks (either by percentage or by absolute amounts), the marginal benefits of use would be unlikely to be constant among users because of differential, individual demand elasticities. Any of the errors to be committed will be magnified by the presumed high inelasticity of demand.

On balance, the above suggests that approximating shortage losses with demand and marginal cost information is likely to be conservative if we use the low marginal supply prices of water in carrying out the evaluation. Despite the difficulties and the conservative estimation, we do apply the integration method to check the shortage index data used above and we carry this out to obtain an estimate of the implicit price elasticity in sections

4.1 and 4.2. This provides a check on the accuracy of the shortage index method.

The social value of shortages is calculated as:

$$\int_{q=q_r}^{q_d} [p(q) - mc(q)] dq \quad (4-14)$$

where  $q_r$  is the quantity after rationing and  $q_d$  is quantity desired in the same time. But this differs from private evaluation of shortages because privately we would be concerned about the integral of willingness-to-pay, i.e., the demand prices  $p(q)$ , over the established market price,  $p(q_d)$ , which is a constant. This should be less than (by its conservatism) or equal to (4-12) above.

$$\int_{q=q_r}^{q_d} [p(q) - p(q_d)] dq = 45.54 SI^{1.60} R \quad (4-15)$$

where  $R$  may be interpreted as equivalent to  $q_d$ . The right hand side is in units of millions of gallons per year and since it is easier to interpret the left hand side as thousands of gallons per quarter, we convert the right to the same units.

$$\int_{q=q_r}^{q_d} p(q) dq - mc_o(q_d - q_r) = .1822 \left\{ \left[ \frac{2Sh}{R} \right]^{1.63} \right\}^{1.60} R \quad (4-16)$$

$$\int_{q=q_r}^{q_d} p(q) dq = 1.1044 (q_d - q_r)^{2.60} q_d^{-1.60} + mc_o (q_d - q_r) \quad (4-17)$$

assuming constant price  $p(q_d)$  and that the shortage is measured by the difference between desired output,  $q_d$ , and rationed output,  $q_r$ . We note that attempting to formulate the demand function as  $p = aq^b$  so that it has a constant price elasticity of demand ( $= -1/b$ ), the equation cannot be solved

for  $b$  indicating that the engineering formula is not compatible with a constant demand price elasticity formulation.

A linear formulation of demand  $p = a + bq$  with  $a$  and  $b$  both functions of  $q$  is necessarily consistent with the engineering model, because it represents a linear approximation to the unknown demand specification. As such we can calculate an arc price elasticity. If we assume  $b = b(q)$ , and recall that  $a = a(q)$  implicitly, we can reformulate (4-17):

$$aq_d + \frac{b(q)}{2} q_d^2 - aq_r - \frac{b(q)}{2} q_r^2 = 1.1044 (q_d - q_r)^{2.60} q_d^{-1.60} + (a + b(q)q_d) (q_d - q_r) \quad (4-18)$$

$$(q_d - q_r) \left( a + \frac{b(q)}{2} (q_d + q_r) \right) = 1.1044 (q_d - q_r)^{2.60} q_d^{-1.60} + a + b(q)q_d (q_d - q_r) \quad (4-19)$$

$$b(q) = 1.1044 \left( 1 - \frac{q_r}{q_d} \right)^{1.60} / \left( \frac{q_d + q_r}{2} - q_d \right) \quad (4-20)$$

$$a(q) = p(q_d) - b(q)q_d \quad (4-21)$$

Assuming a ten percent shortage, i.e.,  $q_r = .9q_d$

$$b(q_d) = -.5549/q_d \quad (4-22)$$

It is clear that  $b(q)$  does, in fact, vary with changes in quantity, but it will also vary specifically with both  $q_r$  and  $q_d$ , so the best that we can calculate is an implied arc price elasticity of a non-linear, non-constant elasticity demand model. On the basis of reasonable estimates of  $q_d$  so that the arc price elasticity is calculated with  $q_d = 800,000$  thousand gallons per quarter, then  $b(q) = -6.936 \times 10^{-7}$ . This is a reasonable estimate, and can be roughly converted into a price elasticity\* if we know the value of the changes in  $a$  and  $b$  as we change  $q$ . From (4-21) and (4-22), we know that  $d b(q)/dq = .5549/q_d^2$  and that  $d a(q)/dq = dp/dq - (d b(q)/dq)q - b(q) = -(db(q)/dq)q$ . The price elasticity is calculated as:

$$\begin{aligned} \frac{dq}{dp} \frac{p}{q} &= \left[ \frac{1}{b(q)} \left[ 1 - p \frac{d 1/b(q)}{dq} - \frac{d(-a(q)/b(q))}{dq} \right] \right] \frac{p}{q} \\ &= p \left[ b(q) + \frac{d a(q)}{dq} + (p-a) \left( \frac{d b(q)}{dq} / b(q) \right) \right] q \\ &= \frac{p}{b(q)q} = \frac{.45}{.5549} = -.81 \end{aligned}$$

\* It also requires that we know the price associated with the equilibrium quantity,  $q_d$ . The engineering formula does not offer such information to us. Further the arc price elasticity uses a demand slope at some point between  $q_d$  and  $q_r$ , although we evaluate it as if it were at point  $q_d$ .

This is a larger price elasticity than those typically found empirically, to assume and it raises some doubt about the engineering shortage losses reported in earlier literature.\*\* We know however, that our estimates using shortage loss functions will be conservative and since these provide much of the justification for regionalization, then our justification of regionalization will also be conservative. With this additional justification of the shortage loss formulae, we continue with questions of regionalization.

#### 4.9. Conclusions

The quantification of shortage losses was a difficult task. Reported shortage losses can be highly subjective, or in some instances, may have neglected the effects of inconveniences which could convince established businesses to leave or potential new business to settle elsewhere.

Nevertheless, using a range of cost factors and physical conditions, it was demonstrated that the threat of shortages should be serious enough to persuade communities to either expand their supply and shortage facilities, or tie into a larger regional supply system.

\*\* We note, however, that the conservatism which is inherent in using economic evaluation (i.e., the inequality implicit in (4-15)) makes us overevaluate the implied elasticity. Whether this can make up for the discrepancy between elasticities reported in Chiogioji and Chiogioji and the imputed elasticities calculated here is problematical.

## CHAPTER V

### INTERBASIN WATER TRANSFER

Chapters III and IV addressed themselves chiefly to water supply regionalization between two or more small communities, and developed tools for estimating firm yields and expected shortages given a long-term average streamflow and a specific water demand.

One of the major project objectives was to study the feasibility of large-scale regionalization projects. Since local water supply sources in densely developed areas with large water demands are either fully appropriated or hopelessly polluted, some form of interbasin water transfer is often the only solution. The two schemes which will be discussed below are:

1. Appropriation of an essentially steady water flow, to be interrupted only during severe droughts on the source stream.
2. Flood skimming, exclusively of flows above a certain flood level.

#### 5.1 The Pros and Cons of Interbasin Water Transfer

Water demand, water supply, and institutional considerations should ideally determine rather than follow the population growth and economic activities of a region. This has not been the case, however, because water supply has been poorly allocated by those who price it. Had pricing historically been applied so individuals paid full social costs the spatial distribution of population would more correctly utilize our water resources. If pricing were flexible, there would never be shortages because while economics is the subject of scarce resources, no economist could ever recognize a shortage if he were properly applying flexible

pricing. This, however, has not been the picture of reality. Prices have been frozen at low, moralistically "just" levels and there have been shortages. Roberts (1971) reports on one example where the water needs exceeded the water supply. This problem was solved in Illinois by hauling water via commercial truckers. In 1970 500 year-round haulers (each traveling an average of 10 miles) supplied 72 million gallons (mg) of water to 6000 rural dwellers. In the 15-year period, 1955-1970, truck water-hauling increased 10-fold. This is a feasible but very primitive method of interbasin water transfer. On the other hand, Quinn (1968) discussed the legal and political restrictions on the transfer of existing water rights and difficulties for growing cities to purchase agricultural water supplies. He also cited numerous negative aspects of water transfer including loss of fast-moving streams for fish, ecological changes due to a decrease in moisture, and legal problems associated with transfer of water between states with the intervention of the Federal Government. Hanke and Boland (1971) demonstrated that with an increase in water rates there was a consistent decrease in water consumption. Both domestic and other sectors of demand were observed to behave in a similar manner with respect to price. The major implication of these results was that regional studies on interbasin water transfers must take explicit account of the effect of price on demand.

Macro-scale water resources planning agencies may take a look at available resources and find transfer of excess waters from one basin to another highly feasible and beneficial from the point of view of overall national or regional economy. The local communities involved, however, and particularly the area from where such transfer water is to be taken,

will invariably generate an amount of opposition so extensive that the project would be doomed to failure. The reasons for this impasse between planners and communities and possible compromise solutions which might be agreeable to all parties were studied.

Schemes involving any diversions of natural water flows from one region to another raised immediate suspicions in the minds of the residents of the "donor" region that their rights and properties are infringed upon without due compensation. Experiences are recalled of political maneuvering in which a community with strong lobbying power has acquired perpetual water rights with little or no decision power left to the donor region. Sometimes these suspicions may be unfounded but they are nevertheless a reality.

Ecological arguments play an important part in most reactions to schemes of major water transfers. Large water diversions may have the potential to raise the water table someplace along the canal or pipeline. Other environmental effects caused by increases or decreases in the natural flow will also be cited, particularly when these effects are adverse in some respect. Environmental effects should be evaluated on an individual basis and no generalization regarding favorable or adverse ecological effects of water diversions can or should be made.

A factor applicable with much more regularity to proposed water transfer schemes, however, is an age-old tradition to consider naturally flowing water essentially as a free commodity, subject only to state-mandated constraints of maintenance of a certain minimum downstream flow release. In the literature review it was found that in most of the proposed diversion schemes it was considered that as long as that certain minimum stream flow was released, all other water could be appropriated as

"excess water," essentially to perpetuity. Little or no incentive is provided to convince the population of the donor region that they are getting a favorable deal themselves. No wonder these communities find little enthusiasm for projects in which they can only see water being taken for somebody else's benefit, and no visible benefits for themselves.

#### 5.1.1 Suggested Compromises to Make Interbasin Water Transfer More Acceptable

A review of the history of previous interbasin water transfer plans resulted in the following two principles:

1. A tangible benefit to the donor region, at the exclusive expense of the receiving region, should be shown. Such benefits may take the form of some level of flood control or a low stream flow augmentation, both of which would require increased dam and reservoir sizes. As an alternative, cash payments could be made directly to the counties primarily affected by the diversion. This alternative, however, should be difficult to administer and could lead to endless litigation because it is virtually impossible to determine the highly interrelated effects of a diversion schedule on individual communities.

When the transfer scheme involves only flood skimming, the benefits to the donor region may be sufficiently convincing themselves. Usually, however, flood skimming projects are of little benefit to the receiving region unless a large amount of unused storage is available, because during flood seasons everyone has more water than he can handle.

2. The diversion agreement should be cancelable by either party with a reasonably long advance notice. Many regions with a water surplus at present, may in the future have water requirements in excess of the present requirements. Whether there are actual plans for such an extensive expansion or not is immaterial; the inhabitants as well as the planners of

such a surplus region usually are not eager to agree to a treaty which would preempt them forever from making use of substantially larger quantities of water.

A 50- to 100-year original water right treaty with a subsequent 10- to 20-year advance notice for cancellation of all or part of the diversion rights would probably make a water transfer scheme from one basin with a surplus to one with a deficit much more acceptable to both parties.

## 5.2 Choice of a Macro-Scale Case Study Area

To select an appropriate case study area for a specific interbasin transfer study, the investigators looked for a major metropolitan area as the water-shortage region. A region outlined in the Army Engineers North-eastern United States Water Supply Study (Quirk et. al, 1974) comprising 22 counties including and surrounding New York City, was chosen. The counties and the presently existing major reservoirs and aqueducts, are shown in Figures 5.1 and 5.2 respectively. The cross-hatch patterns in Figure 5.1 classify the counties in various ranges of population density. Obviously, New York City is the hub of the water demand center, and practically all of the major aqueducts in the region lead toward this center. The water demand of New York Metropolitan Area Region is about 2329 mgd at present and is expected to rise to 5200 mgd by 2020. 1900 out of these 5200 mgd will have to be developed by a new regional program. The reservoir and aqueduct system is capable of delivering such a quantity during a normal year, but in the event of a reoccurrence of a drought like the one of the early 1960's, the shortage could reach disastrous proportions.

Several alternative solutions to this drought problem have been cited in the Army Engineers Study. Due to the large demand these solutions or programs will require between four and nine separate projects. The 14 main

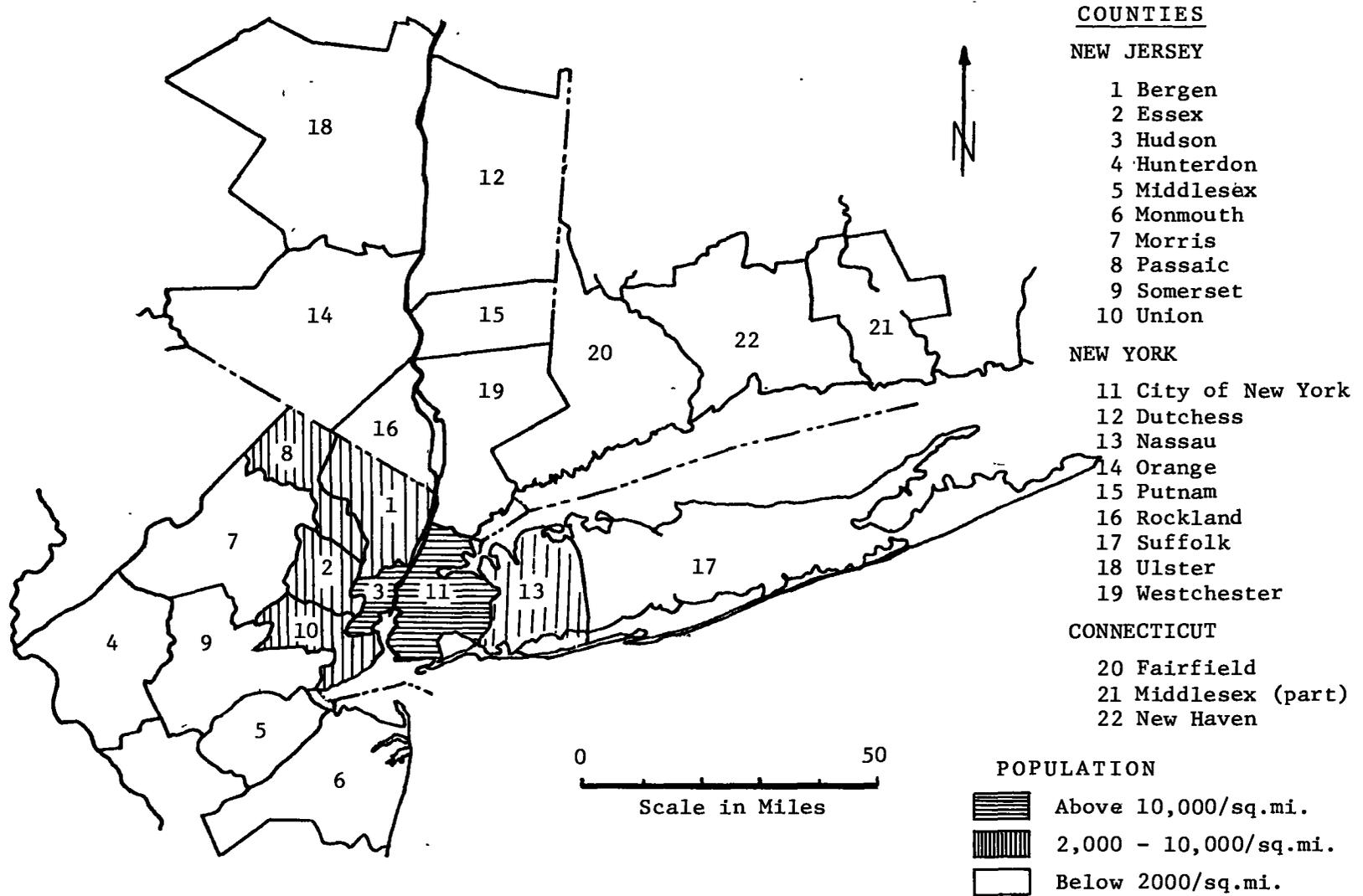


Figure 5.1 New York Study Area

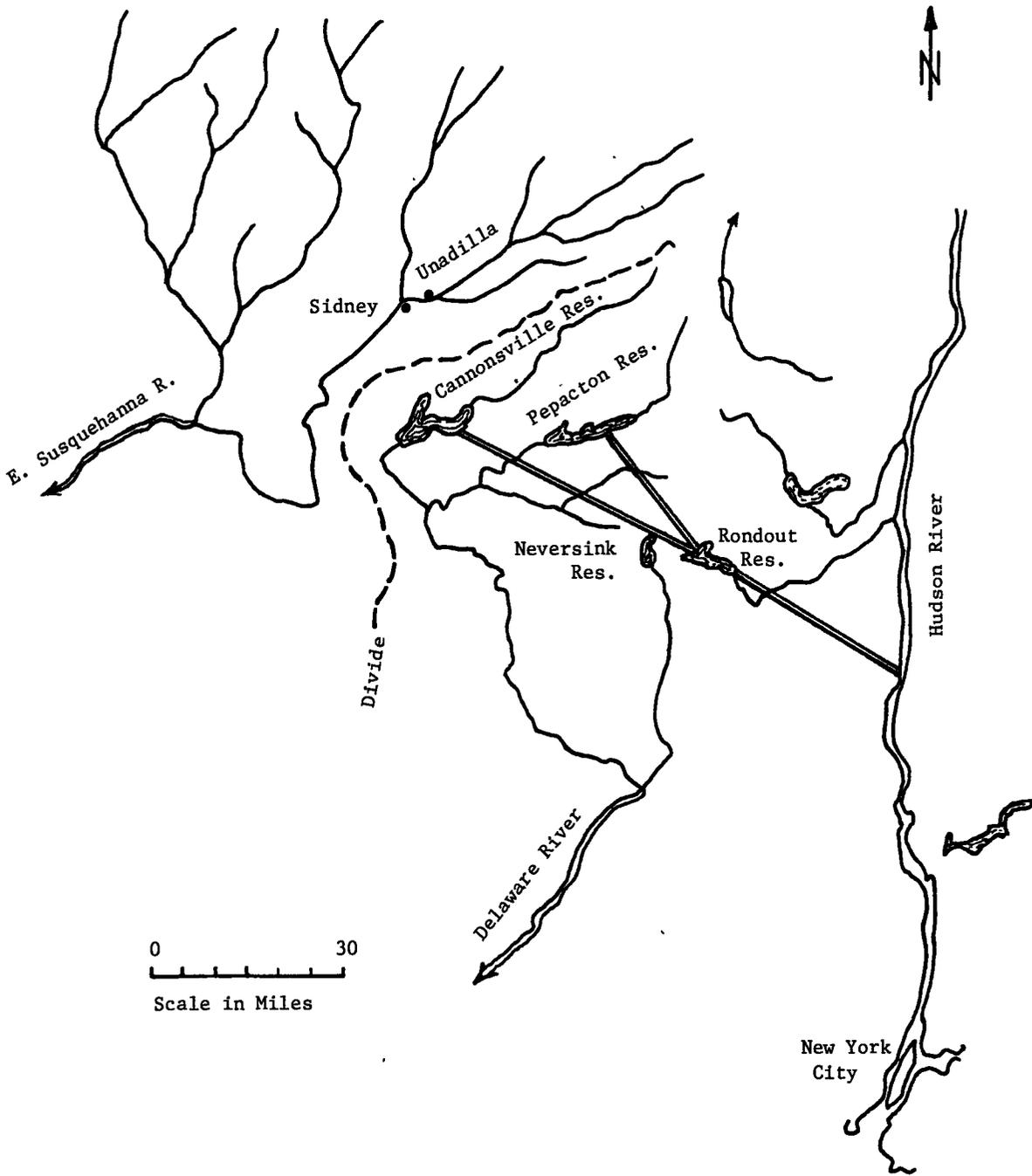


Figure 5.2 Regional Supply System.

projects considered would draw water from such sources as the Hudson, Housatonic, Raritan or Connecticut Rivers, the Delaware River either through flood skimming or Tocks Island Reservoir, Susquehanna River water transfer and ground water from various sources. In this specific case study, the hydrology and some of the costs of water transfer from the upper Susquehanna River to the Cannonsville Reservoir are considered under a few operation schemes.

#### 5.2.1 Population Growth and Density as Indicators of Regional Water Needs

In the Northeastern United States Water Supply Study the needs of the 21 counties surrounding New York City were estimated and listed, together with population in the counties. It could be expected that counties with large populations and a steep increase in population from 1970 to 2020 would also have the largest need for regional water. The regional water needs listed in Table 5.1 were reduced to gallon per day per capita and plotted against population density on Figure. 5.3, with the percent increases in population between 1970 and 2020 shown in parenthesis behind the county names. Even though an eye-fit curve was drawn through the plotted points, no attempt at any mathematical correlation was made. A certain trend of regional water need to increase with increasing rates of population densities seems discernable, but there are too many other factors, like local availability of ground water or polluted local streams, which mask any unique correlation.

#### 5.2.2 Physical Description of the Interbasin Transfer Site

Two major river systems, the Susquehanna and Delaware River basins, are 6 miles (10 kilometers) apart at their closest proximity. Just north of the Pennsylvania-New York border at approximately N42° 05', W75° 20', three possible routes for interbasin water transfer were considered.

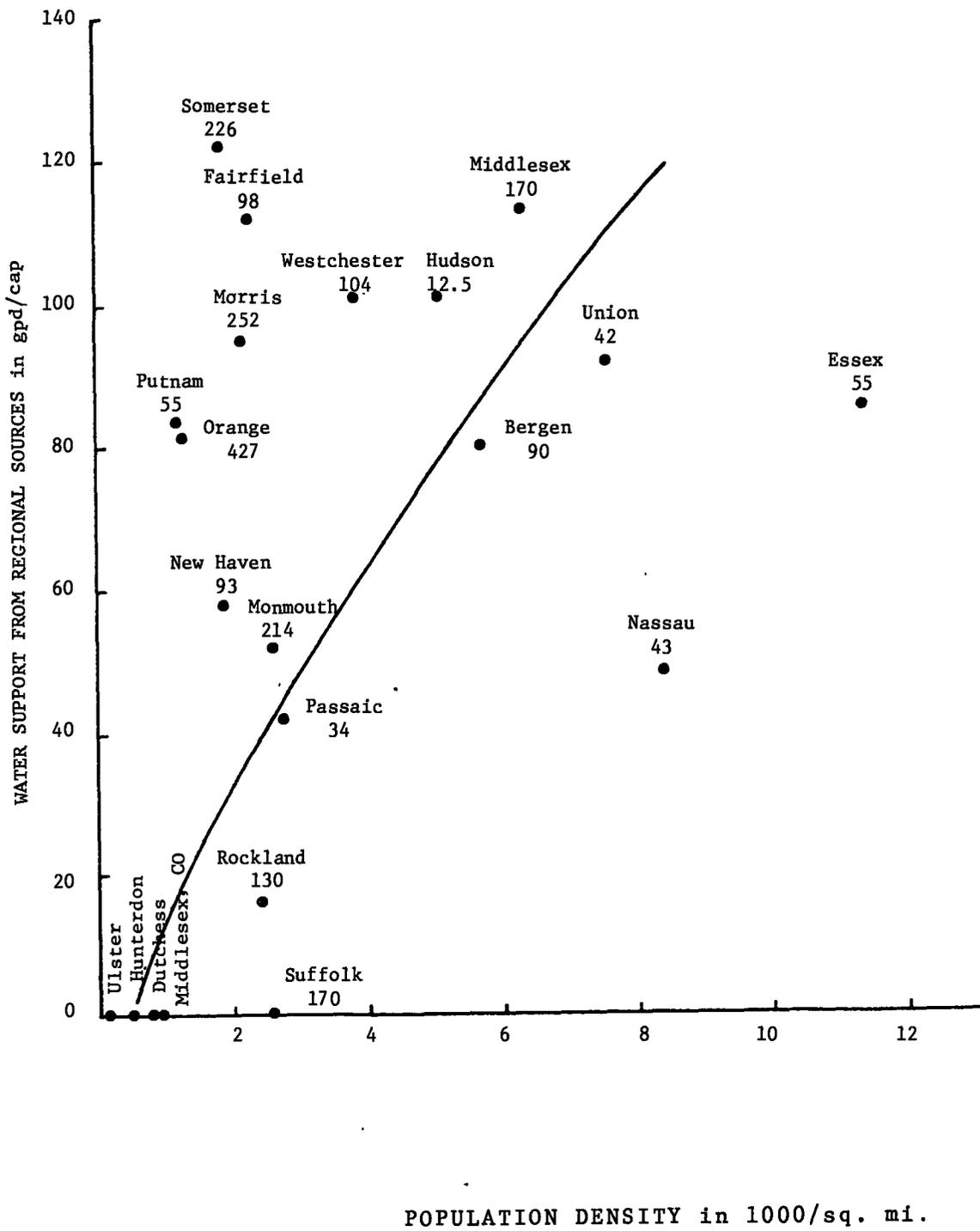


Figure 5.3 Regional Water Needs vs. Population Density

Table 5.1. Estimated Quantities to be Supplied  
by Regional Programs

County	Million gallons per day		
	1980	2000	2020
<u>NEW JERSEY</u>			
Bergen	25	75	130
Essex	10	60	125
Hudson	15	45	80
Hunterdon	(1)	(1)	(1)
Middlesex	20	75	150
Monmouth	0	0	65
Morris	15	55	105
Passaic	0	5	25
Somerset	15	45	70
Union	<u>20</u>	<u>40</u>	<u>70</u>
Total New Jersey	120	400	820
<u>NEW YORK</u>			
Dutchess	(1)	(1)	(1)
Nassau	-	52(2)	96(2)
Orange	-	31	89
Putnam	-	12	23
Rockland	-	0	7
Suffolk	(1)	(1)	(1)
Ulster	(1)	(1)	(1)
Westchester	<u>50</u>	<u>102</u>	<u>178</u>
Upstate New York			
Subtotal	50	197	393
City of New York	<u>100</u>	<u>253</u>	<u>447</u>
Total New York	150	450	840
<u>CONNECTICUT</u>			
Fairfield	25	70	160
Middlesex (part)	(1)	(1)	(1)
New Haven	<u>15</u>	<u>30</u>	<u>80</u>
Total Connecticut	40	100	240
Total Study Area	310	950	1,900

1. Supplied by local sources.
2. Approximately 40 mgd of water used is recovered by recharging the underground aquifers in Nassau County.

The bedrock in this area is of Devonian age composed primarily of the Genesee and Sonyea Groups. These rocks are siltstones, sandstones, and shales. The lower reaches of the Susquehanna River basin are primarily Genesee Group rocks. Butternut Creek, just north has red shales and sandstones in its upper reaches and shale, siltstones, and sandstones in the lower reaches.

Overlying the rocks are Wisconsin and pre-Wisconsin glacial tills, Valley Heads Moraine of Fairchild. Reaches, as much as 100 miles long, along the Susquehanna and Chemung River valleys are composed of uniform-sized sands and gravels suggesting similar source areas (Denny, 1956). The Valley Heads Moraine of Fairchild consists of thick deposits of drift and discontinuous patches of moraine. The moraine is commonly at the base of north-facing escarpments on the adjacent uplands. The common soils in the better-drained parts of the moraine are gray-brown Podzolic soils. The till of Valley Heads subage is olive, massive, dense, and very firm; soil scientists classify it as channery silt loam.

Weather patterns are generally dominated by coastal storms in the Fall, Canadian fronts in the Winter, and westerly storms in the Spring and Summer. Average precipitation ranges from 29 to 35 inches per year (737 to 889 mm/yr.). The average temperature is approximately 48°F; the highest = 90°; the lowest = -16°.

The dominant drought occurred in 1964, with a slow decline in the water table within this area starting in the early 1960's. Less severe droughts occurred in 1957, the early 1940's, and in the 1930's, in order of decreasing severity.

#### 1. The Susquehanna River Basins

The area of interest in the Susquehanna River basin is located above

the gage at Vestal, New York (U.S.G.S. gage 1-5135). This 3960 square mile (10,100 square kilometer) area has a mean flow of 6176 cfs for 28 years of record. The dendritic stream pattern has four main input streams, Butternut Creek and the upper reaches of the Susquehanna above the most northern interbasin transfer site and the Chenango and Tioughnioga Rivers downstream, just upstream from the Vestal, New York gage. The area has been glaciated during the Wisconsin ice age. The soils, therefore, are generally more coarse and allow for quick drainage and high soil water storage. Most of the area is forested with very little urbanization.

## 2. The Delaware River Basins

To consider an equivalent area within the Delaware River the basin above the U.S.G.S. gage located at Montague, New York (U.S.G.S. gage 1-4385) was chosen. This area of 3480 square miles (8900 square kilometer) extent, has a mean flow of 6408 cfs for 21 years of record. One proposed aqueduct would enter the Delaware River basin at Trout Creek near Rock Royal (gage 1-4240). This area was not glaciated, therefore, the natural high soil storage was not available. This area is more densely populated than the Susquehanna River basin just described.

### 5.2.3 Temporal Drought Patterns

One factor which could favor interbasin water transfer would be difference in temporal drought patterns. If, for example, two adjacent river basins were of very different geologic and meteorologic natures so that droughts in the two basins would tend to occur in different seasons, an interconnection between the basins would be mutually beneficial. Each stream could supplement the other during a period of lowest flow.

A comparison of average monthly flows during the drought years of 1957 and 1969 was made for 3 stream gages, each within the Susquehanna and

Delaware Basins. The results were expressed in csm, or cubic feet per second per square mile of drainage basin, and plotted in Figure 5.4. Unfortunately the temporal drought patterns coincide almost exactly, and the basins could not help each other in times of severe droughts.

#### 5.2.4 Comparative Drought Severity

The second drought aspect which was studied and compared for the two basins was the drought severity during the most severe months of 1957 and 1964.

Table 5.2 shows average monthly flows during the months of April to October of 1957, expressed again in units of csm. March flows had been relatively high as shown in Figure 5.4, whereas from April on the flows declined. Through April and May the Delaware Basin shed a somewhat higher quantity of runoff than the Susquehanna basins, but from then on the Delaware basins decreased in flow continuously until October, and at a steeper rate than the Susquehanna basin streams. These quantities thus confirm the geologic comment made earlier that the soils in the glatiated Susquehanna basin have a higher soil water storage capacity which helps in maintaining higher base flows during a prolonged drought.

Average monthly flows during the drought year of 1964 are listed in Table 5.3. These tabulated values demonstrate that the 1964 drought was much more severe than the 1957 drought, and otherwise confirm once more that the glaciated Susquehanna basins had a slightly higher capacity to hold soil water and sustain a base flow in the absence of rain.

#### 5.2.5 Storage Requirements for Given Firm Yields

As a third hydrologic comparison, the storage requirements to provide firm yields between 15 and 50 percent of the mean annual flows were

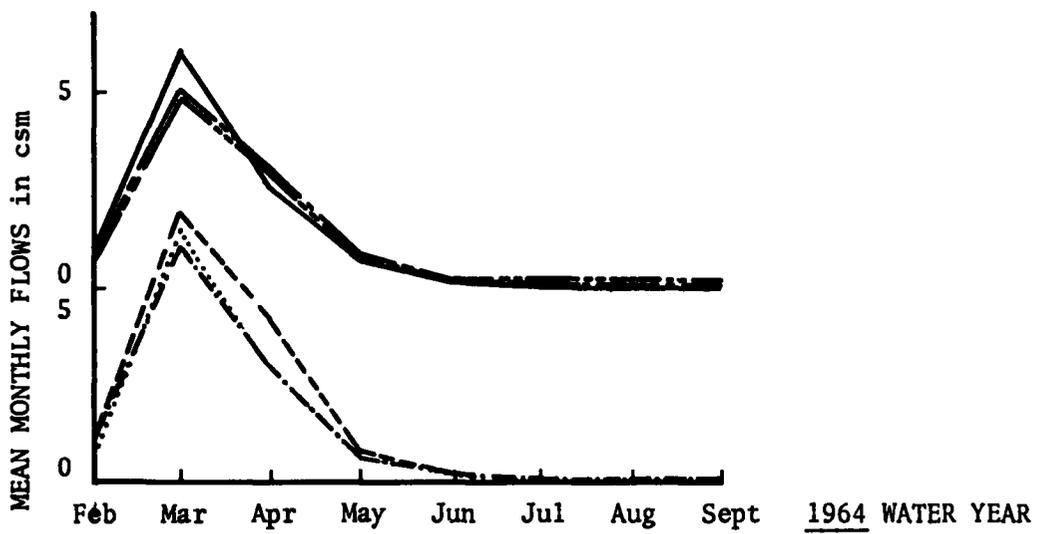
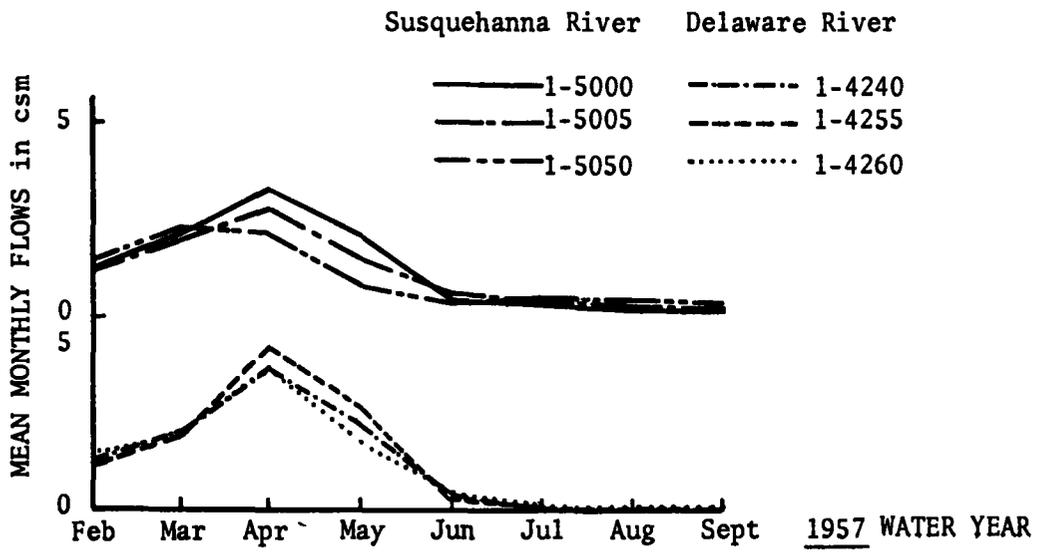


Figure 5.4 Temporal Drought Patterns in 1957 and 1964

Table 5.2. Monthly Streamflows During 1957 Drought

Susq. Gage No.	Drainage Area sq.mi.	Apr	May	June	July	Aug	Sept	Oct
		Flows in cfs per square mile						
1-4965	102	2.86	1.42	.730	.360	.461	.338	.415
1-4975	349	2.73	1.40	.630	.422	.425	.275	.298
1-4990	108	2.60	1.34	.535	.335	.343	.278	.352
1-5000	103	3.25	2.06	.431	.297	.126	.096	.152
1-5005	982	2.92	1.63	.615	.383	.325	.202	.253
1-5020	60	2.68	1.23	.529	.361	.456	.257	.313
1-5050	263	2.13	.88	.439	.317	.508	.390	.312
1-5055	58	3.16	1.36	.511	.304	.138	.444	.392
1-5070	593	2.60	1.22	.523	.442	.411	.312	.285
1-5105	217	3.06	1.50	.516	.498	.355	.450	.353
Susquehanna Average		2.80	1.40	.546	.372	.355	.304	.313
Std. Dev.		.33	.30	.090	.065	.131	.109	.075
Delaware								
Gage No.								
1-4220	142	3.25	1.99	.464	.235	.144	.074	0.115
1-4225	50	3.61	2.35	.440	.192	.101	.082	0.125
1-4230	331	3.54	2.29	.583	.257	.149	.088	0.124
1-4235	9	3.83	2.58	.629	.216	.096	.089	0.121
1-4240	20	3.73	2.23	.410	.220	.062	.058	0.115
1-4255	1.5	4.23	2.56	.217	.136	.026	.028	0.095
1-4260	66	3.70	1.71	.405	.161	.044	.060	0.127
1-4265	593	3.54	2.10	.528	.245	.129	.088	0.135
1-4245	50	3.54	2.23	.410	.220	.062	.052	0.154
1-4250	456	3.62	2.27	.559	.270	.138	.092	0.133
Delaware Average		3.66	2.23	.465	.215	.095	.071	0.124
Std. Dev.		.25	.26	.118	.042	.045	.021	0.015

Table 5.3. Monthly Streamflows During 1964 Drought

Susq. Gage No.	Drainage Area sq.mi.	Apr	May	June	July	Aug	Sept	Oct
		Flows in cfs per square mile						
1-4965	102	4.26	1.21	.105	.053	.028	.017	.023
1-4975	349	3.67	1.05	.254	.118	.095	.081	.053
1-4990	108	3.13	.897	.209	.120	.083	.068	.058
1-5000	103	2.83	.725	.158	.100	.038	.024	.033
1-5005	982	3.19	.976	.254	.150	.101	.070	.060
1-5020	60	3.08	.841	.223	.116	.077	.059	.059
1-5050	263	2.97	.916	.260	.145	.120	.082	.080
1-5055	58	4.06	.991	.136	.028	.017	.016	.014
1-5070	593	3.28	1.128	.307	.142	.100	.080	.068
1-5105	217	4.05	1.097	.278	.243	.100	.065	.066
Susquehanna Average		3.50	0.959	.212	.110	.069	.051	.047
Std. Dev.		0.52	0.160	.067	.067	.041	.031	.025
Delaware								
Gage								
No.								
1-4220	142	3.11	.78	.182	.158	.060	.028	.043
1-4225	50	3.11	.77	.199	.095	.051	.026	.032
1-4230	331	2.91	.82	.213	.137	.073	.048	.047
1-4235	9	3.14	.89	.290	.110	.072	.054	.067
1-4240	20	2.91	.64	.136	.066	.023	.024	.012
1-4227	256	3.03	.87	.212	.134	.058	.039	.037
1-4255	1.5	4.21	.76	.136	.068	.044	.017	.058
1-4260	66	2.91	.69	.195	.050	.036	.028	.039
1-4245				gages eliminated				
1-4250				"	"			
1-4265				"	"			
Delaware Average		3.17	.78	.195	.102	.052	.033	.042
Std. Dev.		0.433	.084	.049	.039	.017	.013	.017

computed and plotted in Figure 5.5. The storage requirements in this comparison were expressed in cfs-months per square mile of drainage area, rather than C/Q as in Chapters III and IV. As could have been expected from the evidence of lower base flows in the Delaware basin, their relative storage requirements were also higher than in the Susquehanna basins.

### 5.3 Alternative Plans for Water Transfer from the Susquehanna to the Delaware Basin

A site near Unadilla, New York, roughly 6 miles (10 kilometers) north of the Cannonsville Reservoir, was chosen for the intake of water to be transferred to the Cannonsville Reservoir. The transfer may take place through a 6-mile pipeline over the divide, dropping the flow into the Cannonsville headwater stream shown in Figure 5.6, or through a tunnel of 9-mile length.

Various alternatives, to be discussed in the following sections, are outlined in Figure 5.7.

#### 5.3.1 Existing Delaware Reservoirs and Aqueducts

The reservoirs and aqueducts (pipelines or tunnels) in the present Delaware System, one of three networks supplying New York and its surrounding communities with water, were shown in Figure 5.2. Reservoir and aqueduct capacities, compiled from data published in the Northeastern United States Water Supply Study (Quirk et. al, 1974) are listed in Table 5.4. According to these data, an additional flow of 322 mgd could be handled by the Cannonsville Tunnel if the Cannonsville reservoir can be maintained at Elev 1150, or 222 mgd at the level of 1040. The conveyance of the supplemental Susquehanna Basin water could run into a bottleneck between the

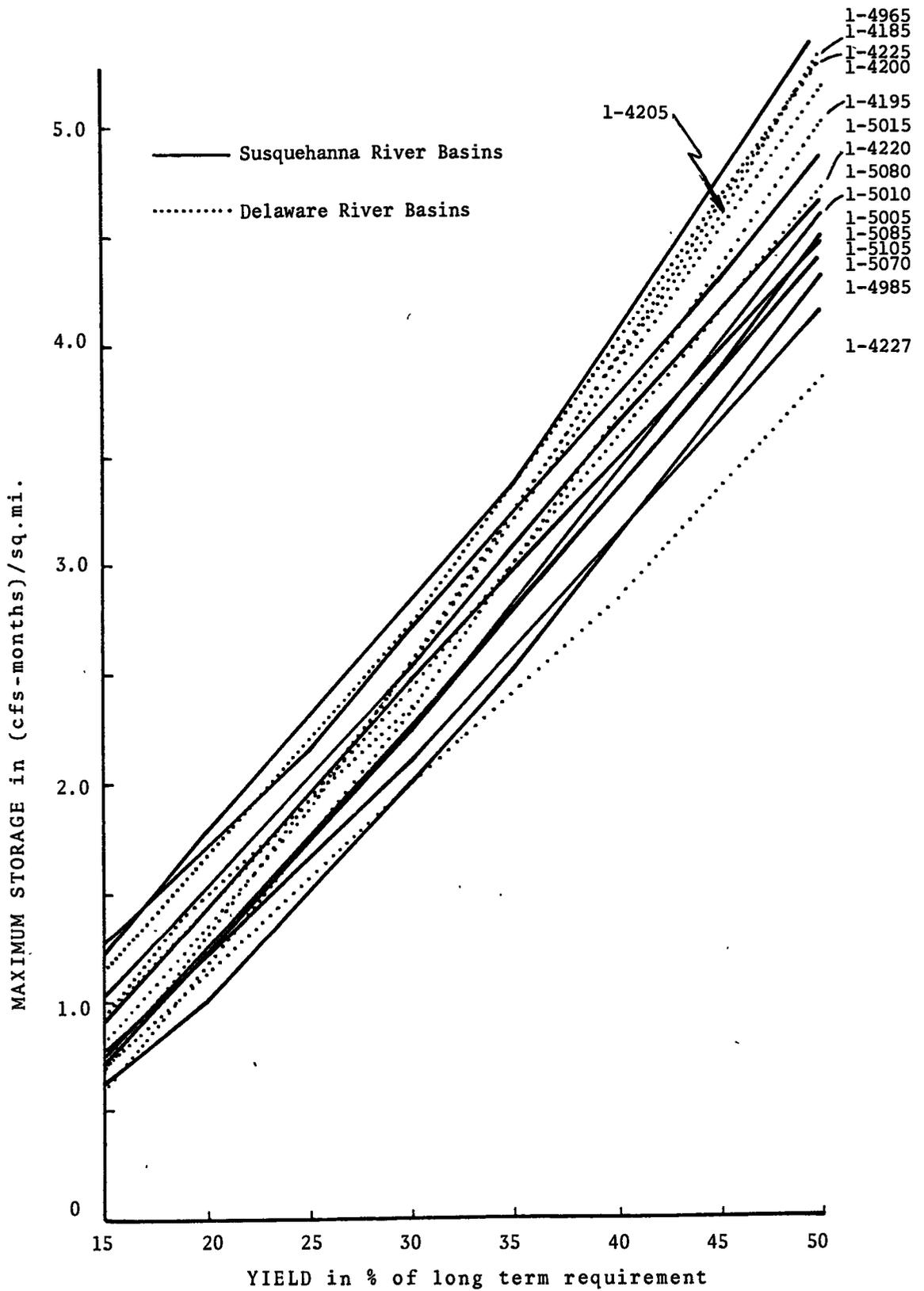


Figure 5.5 Storage-Yield Relationships in Susquehanna and Delaware River Basins.

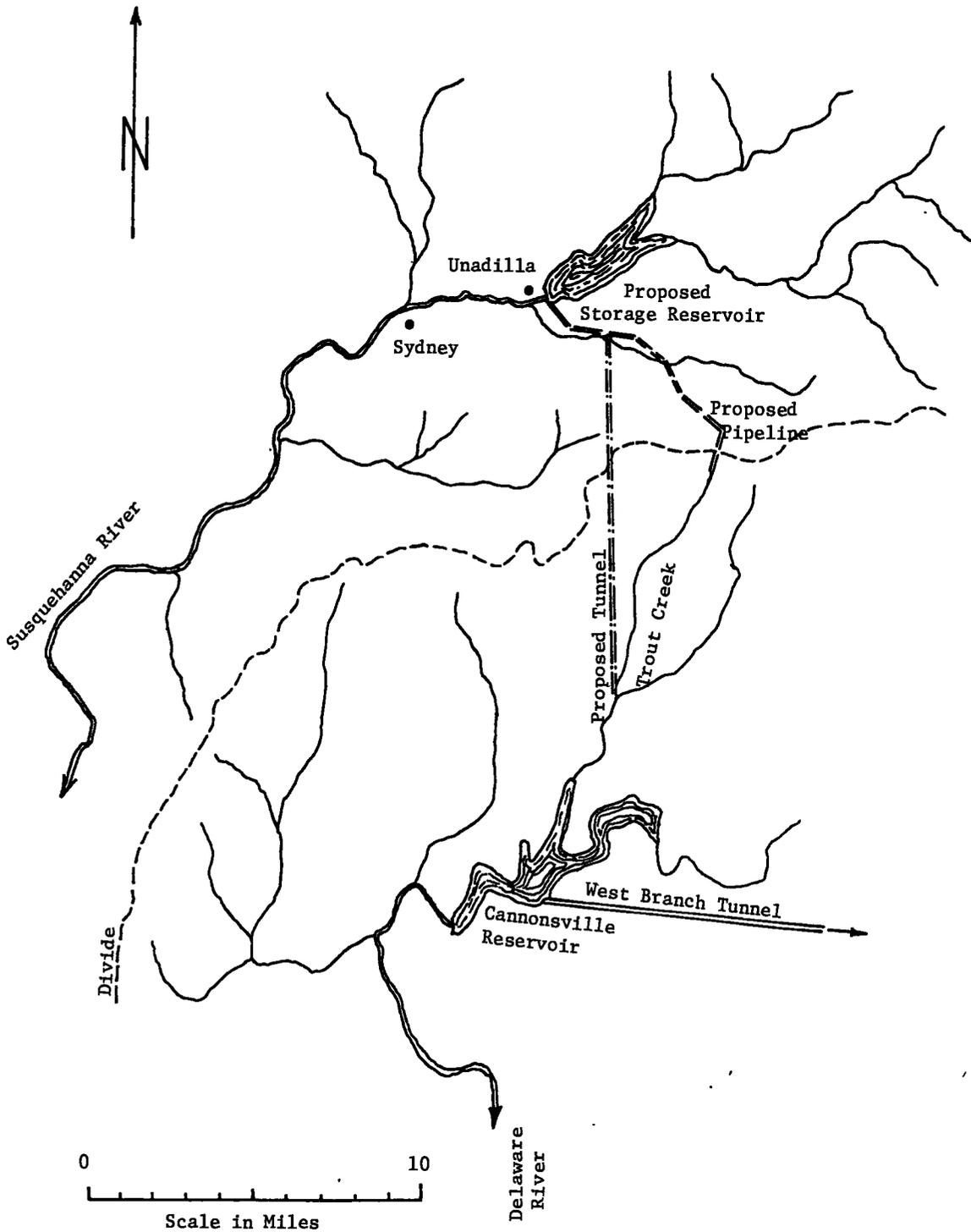


Figure 5.6 Interbasin Water Transfer Site.



Rondout and West Branch Reservoirs, however, the excess storage capacity in the Rondout Reservoir could be used to hold back water when the aqueduct is in full use.

Water transfer from the Susquehanna River should therefore be limited to 300 mgd (460 cfs) as a maximum.

### 5.3.2 Cost Factors Used

Only the major cost items involved in the water transfer alternatives were computed and compared.

For reservoirs, the Black and Veatch formula (3-5) updated to 1975 cost levels and changed to different units

$$C_R = 6000 IR C^{0.6} \quad (5-1)$$

was used, in which  $C_R$  is the annual cost for reservoir construction in Dollars,  $C$  is the reservoir capacity in cfs-month, and  $IR$  the escalation factor, equal to 2.2 to update 1963 costs to 1975.

For annual pipeline costs, the function

$$C_{pi} = 3930 L Q^{0.43} \quad (5-2)$$

was also adopted from Black and Veatch data ( $L$  the pipe length in miles and  $Q$  is flow in cfs) as was the cost function for pumps and pumping station, namely

$$C_{pu} = 1560 Q^{0.90} \quad (5-3)$$

Tunnel costs were adapted from data published by Robbins (1975).

Robbins data expressed costs as a function of tunnel diameter. By using pipeflow formulas and optimizing the tradeoff between increasing costs due to larger diameters and corresponding savings in pumping energy costs the formula for annual tunnel costs

$$C_{tu} = [225,000 + 475 Q^{0.913}]L \quad (5-4)$$

was developed. Q is the flow in cfs and L the length of pipes or tunnels in miles.

An adjustment for pumping heads  $\Delta h > 400$  ft in the pipe and pump station formula was found necessary since Black and Veatch's curves express these costs only as a function of Q. By plotting cost data from miscellaneous sources, the rough cost adjustment coefficient

$$f_h = \frac{\Delta h}{400} \quad [\Delta h > 400 \text{ ft}] \quad (5-5)$$

was developed for equations 5-2 and 5-3.

Pumping power was based on 50% efficiency, the peak power demand charge was \$20 KW/yr, and the energy cost was estimated as 2 cfs per KWhr for steady all-day power and 1 cf per KWhr for night and weekend power, available 50% of the time.

All costs were finally reduced to a cost per million gallons [mg] delivered, and a discount rate of 5-5/8% and a 40-year life for all capital costs was used.

The cost treatment was admittedly cursory, but it was fully realized that there are many minor items involved in a major water transfer scheme that only a rough estimate for comparison purposes was attempted.

### 5.3.3 Flood Skimming Scheme

Flood skimming is probably the most publicly acceptable method of interbasin water transfer, but it should also be a highly inefficient one. In this scheme, the rights to divert water during flows above a specified stage are secured, and diversion is planned for historic high flow months.

As shown in Table 5.4 the unused capacity in the Rondout Reservoir is 12.5 billion gallons [bg], whereas the maximum water rate to be transmitted is 300 mgd, governed by the unused Cannonsville tunnel capacity. Since it is to be expected that flood-skimmed water arrives at a time of lowest need, the 12.5 bg capacity can be filled at most once a year. Thus this volume was assumed to be conveyed at the steady rate of 100 to 400 cfs for 2 months per year. This rate, corresponding to roughly 260 mgd maximum could be planned to be transmitted between February and April each year. Examining the flow records of the Susquehanna River at Unadilla has averaged at least 1500 cfs (equal to the average long-term flow of the river) during these 3 months even during 1965, the driest year, and usually amounts to 3000 - 5000 cfs. It should therefore be relatively easy to acquire the rights to 300 cfs for 60 days anytime during February, March, or April.

Costs for the flood skimming operation will be listed in Table 5.5 under schemes 4a and 4b.

#### 5.3.4 All-Year Transfer by Pipeline

A steady diversion rate at all times including low flow periods is certainly desirable from the water recipient's point of view. To acquire these diversion rights, definite and visible benefits to the donor region should be provided at the expense of the receiving region.

Schemes 1 to 3, summarized in Figure 5.7, provide for an extensive reservoir to be built on the Susquehanna River near Unadilla, New York, with sufficient storage to provide for low flow augmentation and/or flood control on the Susquehanna.

In Scheme 1, any diversion rate must be matched by an equal rate of minimum downstream release. Furthermore, the storage required must be matched by an additional equal storage capacity designated for Susquehanna

Table 5.4. Delaware System Reservoir and Aqueduct Capacities

Reservoirs	Storage Capacity bg	Unused Capacity bg
Cannonsville	96	
Pepacton	140	
Neversink	35	
Rondout	50	12.5
Aqueducts	Conveyance Capacity mgd	Unused Capacity mgd
Cannonsville Tunnel	500	322
Neversink Tunnel	500	360
Pepacton Tunnel	750	384
Delaware Aquaduct (Rondout to W. Br. Res.)	890	105

Table 5.5. Costs of Interbasin Transfer Water

Transfer Flow cfs/mi <sup>2</sup>	0.1	0.2	0.3	0.4
Transfer Flow cfs	98.2	196.4	294.6	392.8
Transfer Volume bg/yr	23.1	46.2	69.4	92.4

Scheme 1a Diversions matched by minimum Susquehanna release.  
 Diversion storage matched by flood control storage.

Min. Susq. Flow cfs	98.2	196.4	294.6	396.8
Required Res. Storage, cfs-mo.	600	1820	3080	4400
Flood Protect. Storage, cfs-mo.	600	1820	3080	4400
Mountain Pass Elev.	1850	1850	1850	1850
Min. Res. Elev.	1020	1020	1020	1020
Max. Oper. Res. Elev.	1048	1066	1078	1088
Max. $\Delta h = \Delta Z_{\max} + 150'$ frict.	980	980	980	980
Ave. $\Delta h = \Delta Z_{\text{ave}} + 150'$	966	957	951	946
Power Demand, MW	16.4	32.8	49.2	65.6
Energy per year, 10 <sup>3</sup> MWhrs	141	278	415	550

Annual Costs in \$10<sup>6</sup>

Reservoir	0.93	1.81	2.48	3.07
Power Demand	0.33	0.65	0.98	1.31
Energy Consumption	2.82	5.56	8.30	11.00
6-mile Pipeline	0.42	0.56	0.66	0.76
Pump Station	0.24	0.44	0.63	0.83
Total Cost \$10 <sup>6</sup> /yr.	4.74	9.02	13.05	16.97
Unit Cost \$/mg	205	195	188	184

Table 5.5 Continued

Transfer Flow, cfs	98.2	196.4	294.6	392.8
Transfer Volume, bg/yr	23.1	46.2	69.4	92.5
<u>Scheme 1b</u> Same as 1a, but using off-peak night power only.				
Night-time Flow cfs	196.4	392.8	589.2	785.6
Prime-time Flow cfs	-	-	-	-
Power Demand MW	32.8	65.6	98.4	131.2
Energy per yr, 10 <sup>3</sup> MW hrs	141	278	415	550
<u>Annual Costs in \$10<sup>6</sup></u>				
Reservoir	0.93	1.81	2.48	3.07
Power Demand (off-prime)	-	-	-	-
Energy Consumption	1.41	2.78	4.15	5.50
6-mile Pipeline	0.56	0.76	0.88	1.00
Pump Station	0.44	0.83	1.18	1.53
Total Cost, \$10 <sup>6</sup> /yr.	3.34	6.18	8.69	11.10
Unit Cost \$/mg	145	134	125	120

Table 5.5 Continued

Transfer Flow, cfs	98.2	196.4	294.6	392.8
Transfer Volume, bg/yr	23.1	46.2	69.4	92.5

Scheme 2a Minimum Susquehanna release equals twice diversion flow.  
No flood control storage.

Min. Susqu. Flow cfs	196.4	392.8	589.2	785.6
Required Res. Storage cfs-mo.	1100	3100	6500	11900
Mountain Pass Elev.	1850	1850	1850	1850
Min. Res. Elev.	1020	1020	1020	1020
Max. Res. Elev.	1058	1078	1099	1112
Max. Δh	980	980	980	980
Ave. Δh	961	951	940	934
Power Demand, MW	16.4	32.8	49.2	65.6
Energy per year 10 <sup>3</sup> MWhr	140	276	410	543

Annual Costs in \$10<sup>6</sup>

Reservoir	0.88	1.64	2.56	3.70
Power Demand	0.33	0.65	0.98	1.31
Energy Consumption	2.80	5.52	8.20	10.86
6-mile Pipeline	0.42	0.56	0.66	0.76
Pump Station	0.24	0.44	0.63	0.83
Total Cost \$10 <sup>6</sup> /yr.	4.67	8.81	13.03	17.46
Unit Cost, \$/mg	202	191	188	189

Table 5.5 Continued

Transfer Flow, cfs	98.2	196.4	294.6	392.8
Transfer Volume, bg/yr.	23.1	46.2	69.4	92.5
<u>Scheme 2b Same as 2a, but using off-peak night power only.</u>				
Night-time flow	196.4	392.8	589.2	785.6
Prime-time flow	-	-	-	-
Power Demand	32.8	65.6	98.4	131.2
Energy per yr. $10^3$ MWhrs	140	276	410	543
<hr/>				
<u>Annual Cost in <math>\\$10^6</math></u>				
Reservoir	0.88	1.64	2.56	3.70
Power Demand (off-time)	-	-	-	-
Energy Consumption	1.40	2.76	4.10	5.43
6-mile Pipeline	0.56	0.76	0.88	1.00
Pump Station	0.44	0.83	1.18	1.53
<hr/>				
Total Cost, $\$10^6$ /yr.	3.28	5.99	8.72	11.76
Unit Cost \$/mg	142	130	126	127

Table 5.5 Continued

Transfer Flow, cfs	98.2	196.4	294.6	392.8
Transfer Volume bg/yr.	23.1	46.2	69.4	92.5

Scheme 3a Same as 1a, but conveying through a 9-mile tunnel rather than 6-mile pipeline over divide.

Min. Susq. Flow cfs	98.2	196.4	294.6	392.8
Required Res. Storage, cfs mo.	600	1820	3080	4400
Flood Prot. Storage, cfs-mo.	600	1820	3080	4400
Cannonsville Res. Elev.	1150	1150	1150	1150
Tunnel Invert	1188	1186	1185	1184
Min. Res. Elev.	1020	1020	1020	1020
Max. Oper. Res. Elev.	1048	1066	1078	1088
Max. $\Delta h = \Delta Z_{\text{max}} + 25'$ frict.	193	191	190	189
Ave. $\Delta Z_{\text{ave}} + 25'$	179	168	161	155
Power Demand, MW	3.2	6.3	9.4	12.5
Energy per yr, $10^3$ MWhrs	26.0	48.8	70.2	90.1

Annual Costs in  $\$10^6$

Reservoir	0.93	1.81	2.48	3.07
Tunnel	2.56	2.84	3.10	3.36
Power Demand	0.06	0.13	0.19	0.25
Energy Consumption	0.52	0.97	1.40	1.80
1-mile Pipeline	0.03	0.04	0.05	0.06
Pump Station	0.10	0.18	0.26	0.34
Total Cost, $\$10^6$ /yr.	4.20	5.97	7.48	8.88
Unit Cost, \$/mg	182	129	108	96

Table 5.5 Continued

Transfer Flow cfs	98.2	196.4	294.6	392.8
Transfer Volume 'bg/yr	23.1	46.2	69.4	92.5

Scheme 3b Same as 3a, but using off-peak night power only. Tunnel size to be increased.

Night-time Flow cfs	196.4	392.8	589.2	785.6
Prime-time Flow cfs	-	-	-	-
Power Demand	6.4	12.6	18.8	25.0
Energy per yr. $10^3$ MWhrs	26.0	48.8	70.2	90.1

Annual Costs in  $\$10^6$

Reservoir	0.93	1.81	2.48	3.07
Tunnel	2.84	3.36	3.86	4.34
Power Demand (off-prime)	-	-	-	-
Energy Consumption	0.26	0.49	0.70	0.90
1-mile Pipeline	0.04	0.06	0.07	0.08
Pump Station	0.18	0.34	0.49	0.63
Total Cost, $\$10^6$ /yr.	4.25	6.06	7.60	9.02
Unit Cost, \$/mg	184	131	110	98

Scheme 3c Same as 3b, but holding pond provided instead of increasing tunnel size

Holding Pond Capacity (2 days of flow) cfs-mo.	6.5	13.0	19.5	26.0
Pond Cost	0.04	0.06	0.08	0.09
Tunnel Savings (see scheme 3a)	0.28	0.52	0.76	0.98
Net Savings over Scheme 3b	0.24	0.46	0.68	0.89
Total Cost, $\$10^6$ /yr.	4.01	5.60	6.92	8.13
Unit Cost, \$/mg	174	121	100	88

Table 5.5 Continued

Transfer Flow cfs	98.2	196.4	294.6	392.8
Flow Duration, mo./yr.	2	2	2	2
Transfer Volume bg/yr.	3.85	7.7	11.6	15.4

Scheme 4a Flood Skimming in February to April; no reservoir or tunnel.

Storage	-	-	-	-
Mountain Pass Elev.	1850	1850	1850	1850
Intake Elev.	1000	1000	1000	1000
$\Delta h = \Delta Z + 150'$ frict.	1000	1000	1000	1000
Power Demand	16.7	33.4	50.2	66.9
Energy per yr. $10^3$ MWhrs	24.0	48.1	72.1	96.2

Annual Cost in  $\$10^6$ 

Power Demand	0.33	0.67	1.00	1.34
Energy Consumed	0.48	0.96	1.44	1.92
6-mile Pipeline	0.42	0.56	0.66	0.76
Pump Station	0.24	0.44	0.63	0.83
Total Cost $\$10^6$ /yr.	1.47	2.63	3.73	4.85
Unit Cost \$/mg	382	342	322	315

Table 5.5 Continued

Transfer Flow, cfs	98.2	196.4	294.6	392.8
Flow Duration, mo./yr.	2	2	2	2
Transfer Volume bg/yr.	3.85	7.7	11.6	15.4

Scheme 4b Same as for 4a, but using different off-peak night power only.

Night-time Flow, cfs	196.4	392.8	589.2	785.6
Prime-time Flow, cfs	-	-	-	-
Power Demand MW	33.4	66.9	100.3	133.8
Energy per yr. $10^3$ MWhrs	24.0	48.2	72.1	96.2

Annual Costs in  $\$10^6$

Power Demand (off-prime)	-	-	-	-
Energy Consumption	0.24	0.48	0.72	0.96
6-mile Pipeline	0.56	0.76	0.88	1.00
Pump Station	0.44	0.83	1.18	1.53
Total Costs $\$10^6$ /yr.	1.24	2.07	2.78	3.49
Unit Costs \$/mg	322	269	240	227

flood control. This arrangement may seem a rather costly one, but it must be acknowledged that it is a sellers market and that any proposal from their side must be a generous one to be accepted.

In Scheme 2, the flood control provision was dropped, but the diversions were matched by minimum Susquehanna releases twice the magnitude of the diversion rate. This scheme may be preferable to Scheme 2 if the river downstream from the reservoir is suffering from serious pollution troubles due to frequent low flows or a stable flow rate is otherwise desirable.

#### 5.3.5 All-Year Transfer by Tunnel

In both Schemes 1 and 2, the water is pumped from the reservoir at elevation 1000 to 1150, over the divide at elevation 1850 by a 6-mile pipeline, and emptied into Trout Creek which runs into the Cannonsville Reservoir. In Scheme 3, the diversion, minimum flow release and flood protection provisions are identical to Scheme 1, but the transfer flow would be conducted to the Cannonsville Reservoir (max. WS. Elev. 1150) by a 9-mile gravity flow tunnel. The water from the Unadilla Reservoir would be pumped only to the tunnel intake, at elevation 1200 approximately, instead of the 1850 ft divide, thus balancing the higher tunnel costs against considerable energy cost savings.

#### 5.3.6 Non-Prime Time Operation

All Schemes, 1 through 4, have a subalternative b, under which all pumping operation would take place during off-peak hours at night and on weekends, pumping twice the rate at a load factor of 0.5. All pump equipment, pipes and tunnels will have to be of double capacity, except in Scheme 3, where an additional Subscheme 3c provides for a small holding

pond in a creek at the intake of the tunnel, to provide an alternative to increasing the diameter of the expensive 9-mile tunnel.

### 5.3.7 Cost Comparison Between 9 Alternative Water Transfer Schemes

In Table 5.5 and Figure 5.8, the major costs are shown for the 9 alternative transfer schemes outlined above. In general, the unit costs in dollars per million gallons decrease (mlg) slightly as the diversion volume is increased, except for Scheme 3 in which the high fixed cost tunnel construction provides for pronounced economies of scale, strongly encouraging a large-scale operation.

In contrast, Scheme 2, providing a downstream release twice the diversion rate, runs into a sharp increase in reservoir capacity requirements, with resulting diseconomies when the diversion rate exceeds 400 cfs [260 mgd] and the minimum Susquehanna River release exceeds 800 cfs. In this instance, the total relative draft requirement on the river approaches  $R/Q = 0.8$  which in turn may require reservoir storage holding over several low-flow years.

The off-prime time pumping resulted in favorable cost reductions, especially for schemes which contain large pumping efforts to the divide. The savings shown in Table 5.5 and Figure 5.8 hinge of course on the assumption of 2 and 1 cfs per KWhr for prime and off-prime time power use. These cost coefficients may at this time be somewhat high, which should offset, however, the lack of any maintenance and operation costs in the comparison. In Schemes 3b and 3c it is shown that a small holding pond to allow the tunnel intake to receive water at a fluctuating rate and release it steadily seems to be made less expensive than modifying the tunnel diameter to accommodate twice the flow.

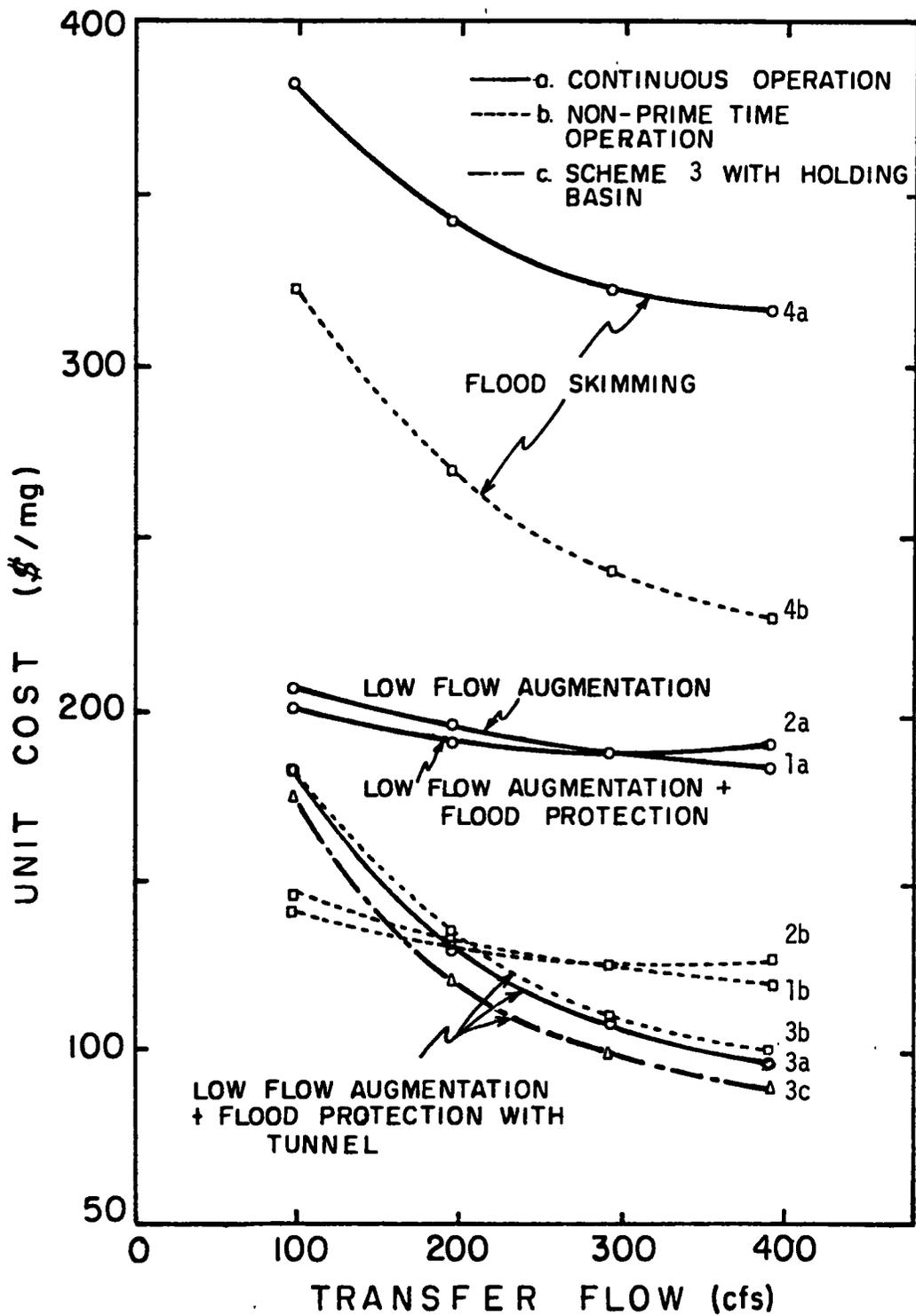


Figure 5.8 - Unit Cost Comparison for Water Transfer Alternatives

Finally, the alternative of plain flood skimming during 2 months of the year, even though avoiding the need for a reservoir, seems to almost double the unit water costs because the facilities all have to be built full-size but will operate only 16.7% of the time, or even 8.3% of the time in Scheme 4b.

#### 5.3.8 Marginal Cost of Flood Control Provisions in Addition to Low Flow Augmentation

It was mentioned earlier that the provision of matching the diversion rate with an equal minimum downstream release, plus matching the firm yield storage volume with additional flood protection storage may seem unduly generous. Table 5.6 below shows however, that the flood storage addition increases the unit cost of the diverted water by only \$11 to \$14 per million gallons, not too high a price to pay for some good will. It remains to be studied in detail however, whether large reservoirs can be built safely near the site chasm.

Table 5.6. Marginal Cost of Flood Control in Schemes 1, or 3

Transfer volume, bg/yr	23.1	46.2	69.4	92.5
Res. storage, incl. flood control, cfs-mo.	1200	3640	6160	8800
Res. storage, excl. flood control, cfs-mo.	600	1820	3080	4400
<hr/>				
Res. cost, incl. flood control, $\$10^6$ /yr.	0.93	1.81	2.48	3.07
Res. cost, excl. flood control, $\$10^6$ /yr.	0.61	1.19	1.63	2.02
<hr/>				
Marginal cost $\$10^6$ /yr.	0.32	0.62	0.85	1.05
Marginal unit cost \$/mg	14	13	12	11

### 5.3.9 Monetary Compensation for Water Transfer

Instead of providing low flow augmentation and/or flood control, a monetary compensation could be paid to Susquehanna communities. The savings achieved by only releasing the minimum state-mandated flow release, would vary between \$21/mg for 100 cfs diversion and \$14/mg for 400 cfs. This would be equivalent to total savings of \$420,000 and \$1,300,000 respectively, which might be attractive as a fair compensation.

### 5.4 Generalization of High Flow-Skimming Processes

The work thus far presented as a case study of integration of the Susquehanna with New York water supplies stands quite complete. However, it is only a case study and it represents a special case (high flow period excess reservoir capacity) with the result that it hides much interesting detail about the problem and the approach used. Much, for example, is hidden specifically in the hydrologic formula (4-5) which originated in this report with equation (3-2) and Figure 3.7. The reported formula varies in the parameters between equations (3-2) and (4-5), the Black and Veatch "Western" formula and our own "Eastern" formula and is shown in Figure 4.3. The magnitude of this discrepancy lays the basis for interest in a theoretical treatment of interbasin transfer using high flow skimming under non-special case conditions.

Equations (3-2) and (4-5) express amount of safe-yield flow,  $R$  (or  $Y$  in 4-5), per period of time as a function of reservoir capacity,  $C$ , and stream flow,  $Q$ , per period of time. The equations are not unlike production functions and can readily be transformed into Cobb-Douglas like functions with constant returns to scale:

$$R = 1.32 C^{.733} Q^{.267} \quad \text{from (4-5)} \quad (5-6)$$

and

$$R = .51 C^{.27} Q^{.73} - .15Q \quad \text{from (3-2)} \quad (5-7)$$

although the latter does not have constant returns or Cobb-Douglas like form because of the  $-.15Q$ . Interpreting these equations as production functions the exponential coefficients of C and Q are the efficiency parameters of capacity and streamflow leading to safe-yield flows.

We know, however, that the functional forms involved are considerably more complex than (3-2) and (4-5) represent them because the stochastic, probability modelling of hydrologic variation in subunits of time of the period for which R and Q are defined has all been collapsed into a constant parameter. This is precisely why (3-2) and (4-5) vary over hydrologically different areas. Yet, it is also such variation in the functional form that we would want to capture as we choose the amount of interbasin skimming flows that are cost minimizing. This section sets up such a model.

Equations (5-6) and (5-7) may be made more amenable to interpretation in the current instance by rearranging so as to express C as a function of Q and R, the two flow variables, each of which are associated not only with mean levels, but also variations over subperiods of time<sup>1</sup>.

$$C = .684 R^{1.364} Q^{-.364} \quad \text{from (5-6)} \quad (5-8)$$

and

$$C = \left( \frac{1}{.51} \right)^{\frac{1}{.27}} \left[ R - .15Q \right]^{\frac{1}{.27} - \frac{.73}{.27}} Q^{\frac{.73}{.27}} \quad (5-9)$$

Since (5-8) is more tractable, we take that as the point of departure, introducing a generalized concept of reservoir requirement.

<sup>1</sup> We define R, Q, and E (interbasin water flow) as average annual flows derived from monthly (or weekly) flows  $r_1$ ,  $q_1$ , and  $e_1$ . Variances referred to in the text are over such subperiods,  $_1$ .

It is true that the volume of E will alter the efficiencies of C and Q in producing R. We find it easiest to generalize by suggesting that the reason parameters in (5-8) and (5-9) vary is because of hydrologic variations in Q, vQ, demand variations in output requirements, given water prices, vR and the correlation between monthly streamflows and required outputs,  $\rho_{vQvR}$ , more simply denoted  $\rho$ . Measuring vQ, vR and  $\rho$  as variations from the "Eastern" conditions under which (4-5) was derived, (5-8) can be restated more generally, accounting for E, as

$$C = .684 R^{1.364} + \alpha_1 vR + \alpha_2 \rho (Q + E)^{-.364} + \alpha_3 v(Q + E) + \alpha_4 \rho \quad (5-10)$$

where  $\rho$  is calculated as the correlation, between monthly streamflows, augmented by monthly interbasin transfers, and required outputs.

Equation (5-10) is quite general in that it shows that capacity may be reduced, holding R constant, because of the effective augmentation of the streamflow, (Q + E) larger than Q in the base of the rightmost term of (5-10). It also shows however, that capacity will have to be augmented in order to hold the extra water, E, if previously during high peak flows capacity was fully utilized. Lastly, (5-10) shows that an increased capacity will increase the efficiency of Q, own-system streamflow without augmentation, because of the larger existing reservoirs. It is expected that  $\alpha_1 > 0$ ,  $\alpha_2 < 0$ ,  $\alpha_3 < 0$ , and  $\alpha_4 > 0$ , so that with high flow skimming which increases the v(Q + E) as well as moderately increasing  $\rho$  (under very general conditions) will likely increase the exponent of R and leave the exponent of (Q + E) ambiguously changed but with some expectation that it decrease. The formula in (5-10) and null hypothesis presented here are subject to test, but here are submitted only to a weak test. That test is the demonstration that in going from (5-8) to (5-9) with implied increases in vQ as well as in vR and

$\rho$ , we would expect  $\partial C/\partial Q$  to increase and  $\partial C/\partial R$  to decrease. This does occur as verified by inspection of (5-8) and (5-9), deleting the  $(-.15Q)$  in the bracketted term of the latter so as to avoid the need to evaluate the partials at specific C, R, and Q values.

If we accept formula (5-10) as the reservoir capacity determining equation for the interbasin transfer recipient region then its analog for the donor region would be:

$$C = .684 R^{1.364} + \alpha_1 vR + \alpha_2 \rho (Q - E)^{-.364} + \alpha_3 v(Q - E) + \alpha_4 \rho \quad (5-11)$$

where the parameters,  $\alpha_1$ ,  $\alpha_2$ ,  $\alpha_3$  and  $\alpha_4$ , are identical to those in (5-10) but where  $\rho$  is defined as the change in correlation (from "Eastern" conditions without high flow skimming) of required output and monthly streamflow minus monthly transfer loss rate.

The problem as now defined is one of minimizing the sum of water system costs, capacity costs, piping costs and shortage losses, by choosing optimal values of E,  $R_1$  and  $R_2$ . That is to be done subject to the inequality constraints that actual average annual demands (given prices),  $D_1$  and  $D_2$  in communities one and two, be respectively greater than or equal to outputs,  $R_1$  and  $R_2$ . This prevents the water systems from forcing consumers to take more water than they desire. Computationally it suggests that the optimization be done using Kuhn-Tucker conditions rather than the ordinary equality constraint conditions, but these are simple enough suggesting that water supply equal water demand so that there are no shortage losses or there are no shortage losses or there are marginal costs of the demand constraints and coexisted shortage losses. These produce less computational difficulty than does the partial condition with respect to E, which involves evaluation of

the effects changes in E have on  $\rho$  and  $v(Q + E)$  which themselves are hydro-logic conditions that will vary from case to case.

Without presenting a solution, the problem is represented by the following notation:

$$\text{Min } L = C_{R_1} + C_{R_2} + C_p + SL_1 + SL_2$$

choose

$$R_1, R_2, E \quad \text{ST. } R_1 \leq D_1, \quad R_2 \leq D_2$$

which is equivalent to unconstrained Min S =

choose

$$R_1, R_2, E$$

$$\begin{aligned} & \left[ .684R_1^{1.364} + \alpha_1 vR_1 + \alpha_2 \rho_1 (Q_1 + E)^{-.364} + \alpha_3 v(Q_1 + E) + \alpha_4 \rho_1 \right]^{.6} \\ & + \left[ .684R_2^{1.364} + \alpha_1 vR_2 + \alpha_2 \rho_2 (Q_2 - E)^{-.364} + \alpha_3 v(Q_2 - E) + \alpha_4 \rho_2 \right]^{.6} \\ & + 62,000 E^{.43} M + d 180,000 E^{.90} + 50,000 EM \\ & + d1065 \alpha \left\{ \left[ \frac{D_1}{Q_1 + E} - \beta \right]^\gamma \right\}^{1.63} R_1 + d 1065 \alpha \left\{ \left[ \frac{D_2}{Q_2 - E} - \beta \right]^\gamma \right\}^{1.63} R_2 \\ & + \lambda_1 (R_1 - D_1) + \lambda_2 (R_2 - D_2) \end{aligned}$$

where M is miles between system one and two, d is an appropriate discount factor converting flow losses into present values, and the quantity units are in correct units as expressed by equations (3-5), (3-16), (3-17), (3-18), (4-5), (4-6), and (4-9).

A computation solution is not easily computed but is certainly possible and feasible. Much more work remains to be done, econometrically fitting the generalized formula of which (5-10) and (5-11) are a part. This can be

accomplished with readily available data if pooling of hydrologic regions is undertaken. Some work would need to be done with the shortage loss functions to make them more amenable to the implicit hydrologic variability in (5-10) (5-11) so that they would show losses, for example, even when  $R = D$  and so that the constraints that  $D_1 \geq R_1$  and  $D_2 \geq R_2$  could be relaxed with a water system stochastically supplying slightly more output than what was demanded so as to account for the implicit hydrologic probabilities in the underlying function (4-5).

### 5.5 Conclusions

The topic of Interbasin Water Transfer was discussed from a sociologic, hydrologic and economic point of view. As a case study the possible supplementation of the New York Region with surplus water from East Branch of the Susquehanna River was studied. Nine alternative schemes were compared, all of which offer some visible benefits to the donor region, and all of which should fit into remaining unused storage and conveyance capacities in the Delaware Supply System. A generalization of the model to interbasin, high flow skimming processes was made.

## CHAPTER VI

### REGIONALIZATION, LAND VALUES AND DISTRIBUTION

This chapter departs from the preceding by switching our focus from water supply regionalization by integration to regionalization by extension. It also departs in ceasing to focus solely upon water supply alone, but here treats the subject of joint water supply and sewage treatment. The frequent linkage of the latter with the former in providing new community growth makes it all the more desirable to treat them jointly empirically. Because of the small size and incremental nature of typical extension projects which involve only water supply, we find it practically possible to locate a suitable case study area only when the two are linked. For whatever reasons, good and bad, we then divert ourselves somewhat from foregoing work.

#### 6.1 Theoretical Background for Measuring Distribution

Water and sewerage investments frequently result in an improvement in the well being of the households connected to the systems relative to private supplies. In many cases the existence of a distributed water source along with sewerage service implies an ability to locate at greater density (or to locate at all) relative to having no common source and service. Aesthetics, health and convenience should all be improved by such measures. The cost of private maintenance is removed when service is communal.

As a consequence of this, one might reasonably expect that householders would place a value upon being connected to piped supplies and sewers that is well in excess of the amount actually paid for these

services. This implies that, other things being equal, the value of a house that obtains the services would be greater than that of one that does not. In contrast to the water/sewerage "market", which does not work very well because there is not a host of suppliers able and willing to compete effectively with the water/sewerage undertaking, the housing market may consist of large numbers of competitive buyers and sellers, and, where public housing regulation is minimal, there is opportunity for the market to reveal the effective willingness of people to pay for water and sewerage facilities.

To illustrate, suppose an individual is willing to pay up to an additional \$100 for piped water supply. He implicitly (or explicitly) estimates the present worth to him of the benefits of piped water net of the present worth of the water charges he expects to pay as a result of having a connection and this represents \$100. From the point of view of the water market, \$100 is consumers' surplus (i.e., the difference between the maximum amount that he would pay if he had to, and the amount that he actually does pay). This consumers' surplus is identifiable if we look into transactions in the housing market but it is not so if we isolate analysis in the water market. This result follows from observation of the constancy of water/sewerage price schedules within communities\* and the

---

\*In a sample of thirty firms regulated by the Pennsylvania Public Utility Commission, the average years per price change (over a 20 year period, 1955-1975) was 17.3 years for private firms, 15.8 years for municipal authorities which sold regionally outside their boundaries, and 13.9 for municipal firms.

consequence that we can econometrically identify only the supply or municipal pricing curve and not the demand curve. The supply and demand curves are not so constrained in the housing market, in fact, demand is held constant in large open housing markets with supply shifting so as to identify the housing market demands - for housing with and without piped service. Since an individual can only obtain water/sewerage (w/s) by purchasing a house with it, then observation of the differential between the two types of housing reveals how much more an individual would have been willing to pay for w/s than what he was actually charged. This differential represents part of the distributional impact of w/s service provision.

In measuring this impact, we must deal with the conditions that exist in the housing market which affect whether the value that can be obtained there measures the full willingness-to-pay. We must deal with the statistical problem of how to measure the impact, given our perception of the housing market. Finally, we must deal with the subsidiary problem of what data to use in the statistical model. These will be discussed in turn below.

## 6.2 The Housing Market

The object of the study is to make use of the relatively competitive nature of the housing market to determine benefits. As previously analyzed (Bahl, Coelen and Warford (1975)), the analysis is particularly facile in developing countries, where installation of water and sewerage facilities often takes place after houses have been occupied. In developed countries, on the other hand, these facilities are normally installed only at the time of construction and in these cases changes in land prices will simultaneously reflect all the improvements inherent in a property as it goes through the development transition. This complicates the analysis.

Clearly, land<sup>\*</sup> markets rarely are perfect models of perfect competition, and to the extent that they diverge from the ideal, they become less useful for our purposes. However, aside from areas in which there is a large degree of public intervention, usually in the form of public housing or rent control, this market represents a considerable improvement on the use of revenue from water sales as a benefit measure. In the context which we are now concerned about the housing market, its one feature that most suits our current purposes is the high degree of intracommunity migration that occurs. In this country especially during the late 1960's and 1970's, the "urban turn-around" testifies to this and gives us assurance that there is competition for rural and suburban land precisely relative to urban and other serviced suburban land. The main question to be faced, therefore, is whether or not increasing values in the housing market correctly capture the effects of the increase in demand for improved properties. In other words, is the increased consumers' surplus in the water market transferred to an equivalent shift in the area under the property market demand curve? And, if so, under what conditions are expenditures on properties also increased by this amount?

The first step in answering these questions requires consideration of the nature of the housing market. Since the impact of the infrastructural improvements will be an increase in demand for the houses affected, the resulting price increases will not be a perfect indicator of benefit unless certain conditions hold. The following two conditions are sufficient

---

\* The terms, land market, housing market and property market, are used interchangeably, but virtually all increments in valuation are perceived to be attributable to the land itself.

but not necessary for such occurrence:

- (a) the slope of the demand curve does not change; and
- (b) the supply of housing is perfectly inelastic.

Consider the implications of conditions (a) and (b). First, if the demand schedule for housing in the project area changes, one might expect it to become relatively more inelastic--there are fewer good substitutes now that the house has piped-in water. That is, it would take a greater price increase to bid an individual away from a house with water than it would when the same house did not have public water supply. This condition is consistent with a downward sloping demand curve for the good, water supply, itself. Such a change in the slope of the demand schedule implies that the increase in property values will underestimate the full value of a regional water supply/sewerage project. As to the supply inelasticity, presence of elasticity means that, as the price of properties in the affected area is bid up, property owners endogenously change the quantity supplied, and this of course leads to a different equilibrium market price than that which would have been established with a stable supply. In the context of new community growth, this latter issue is a critical one, forcing a wedge between what people would be willing to pay and what they do actually pay.

A simple and familiar model suggests that there are, at least, certain assumptions under which benefits and increased expenditures on property are equal.\* In an area receiving new water supply (the project area), the housing demand function (before the project) might be written

---

\*This model is based on the earlier work reported in Bahl, Coelen and Warford (1973).

generally as:

$$q_d = g(q)_d \quad (6-1)$$

and, again, for simplicity the housing supply is a constant:

$$q_s = k \quad (6-2)$$

It follows that the market equilibrium price can be derived as:

$$p_e = f_1 \{g(q_d), k\} \quad (6-3)$$

A measure of consumers' surplus is:

$$c = \int_0^k g(q_d) - p_e k \quad (6-4)$$

The effect of a water supply project providing each house with water can be shown through a shift in the demand curve from its initial position. For the same fixed quantity of housing, residents would now be willing to pay a higher rent--the demand curve has shifted upward. Let us assume that the new demand is:

$$q_d = h(q_d) \quad (6-5)$$

Consumers' surplus is now measured:

$$c' = \int_0^k h(q_d) - p'_e k \quad (6-6)$$

where  $p'_e$  is defined:

$$p'_e = f_2 [h(q_d), k] \quad (6-7)$$

The increase in consumers' surplus between the two periods ( $\Delta c$ ) is:

$$\Delta c = c' - c = \int_0^k g(q_d) - p'_e k - \left\{ \int_0^k h(q_d) - p_e k \right\} \quad (6-8)$$

$$\Delta c = \int_0^k g(q_d) - \int_0^k h(q_d) - \Delta p_e k$$

where  $\Delta p_e = p'_e - p_e$

The increase in net benefits ( $\Delta B$ ) of the water project to residents of the area is equal to the increase in price times the quantity supplied ( $\Delta p_e k$ ) plus any increase in consumers' surplus, i.e.,

$$\Delta B = \Delta p_e k + \Delta C = \left[ \int_0^{q_d} g(q_d) - \int_0^{q_d} h(q_d) \right] - \Delta p_e k + \Delta p_e k \quad (6-9)$$

$$\Delta B = \left[ \int_0^{q_d} g(q_d) - \int_0^{q_d} h(q_d) \right] \quad (6-10)$$

Now if we assume the shift in the housing demand function to be such that  $\Delta C$  is zero, that is, consumers' surplus remains constant, then from (6-8):

$$\Delta C = \left[ \int_0^{q_d} g(q_d) - \int_0^{q_d} h(q_d) \right] - \Delta p_e k = 0 \quad (6-11)$$

$$\Delta p_e k = \left[ \int_0^{q_d} g(q_d) - \int_0^{q_d} h(q_d) \right] \quad (6-12)$$

and from (6-10):

$$\Delta p_e k = \Delta B \quad (6-13)$$

Given the assumptions behind this simple model, the benefits of a water supply project could be fully measured in two steps. The first is revenues derived directly through sales in the water market. The second is a measure of the transferred consumers' surplus (from water to property markets and is defined by equation (6-13)). Their sum gives an unbiased measure of project benefits.  $\Delta B$ , in equation (6-13) is proportional to the increase in house prices, where the constant of propor-

tionality is the stock of housing. If equation (6-11) does not hold, then there is both a change in housing prices and a change in consumers' surplus and the net benefits of the project are measured as in equation (6-10).

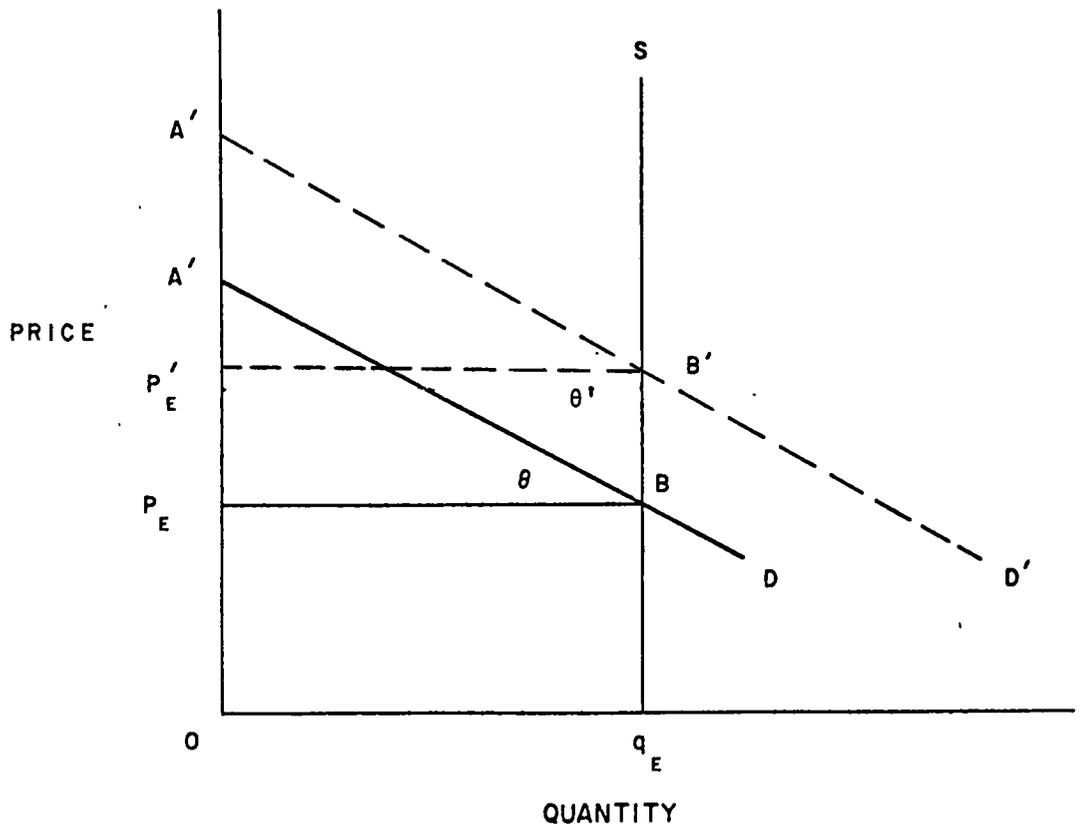
The same conclusions can be reached by graphical analysis. Suppose the market for property looks as pictured in Figure 6.1, where for simplicity the demand curve has been drawn linearly and the supply curve perfectly inelastic. The original demand curve is given by D. Supply is given by S. The area  $P_E B q_E O$  is the pre-investment expenditure on properties. The total willingness-to-pay for these properties is given as  $AB q_E O$ . Consumers' surplus is the difference,  $ABP_E = AB q_E O - P_E B q_E O$ .

Assume that, after a water/sewerage investment, there is a parallel shift in demand to  $D'$ . The area,  $A'B'BA$ , is, by definition, equivalent to benefits due to the investment that are not captured by sales in the water/sewerage markets themselves. That is,  $A'B'BA$  is definitionally equivalent to the increase in willingness-to-pay area. Thus,  $A'B'BA = A'B'q_E O - AB q_E O$ . The question becomes one of trying to show that the additional consumer surplus ( $A'B'BA$ ) is equivalent to the increase in expenditures on the property. The increase in the expenditures is determined by  $\Delta P \cdot q_E$  (since  $q_E$  is constant).  $\Delta P$  is, of course, the change in equilibrium price:  $\Delta P = P'_E - P_E$ . The total change in expenditures is given by the area of  $P'_E P_E BB'$ .

It is necessary to show that  $P'_E P_E BB'$  is equivalent to  $A'B'BA$ . From the simplest theorems of plane geometry, it can be shown that  $\theta = \theta'$ ,  $B'P'_E = BP_E$ , and the intersection of  $BP_E$  and  $B'P'_E$  with  $OA$  and  $OA'$  respec-

FIGURE 6.1

THE MARKET FOR PROPERTY



tively are right angles. These are sufficient conditions to guarantee that the areas  $A'B'P'_E$  and  $ABP_E$  are equal. Construction was made so that:  $A'B'BP'_E - A'B'P'_E = B'BP_E P'_E$ . It is evident that  $A'B'BP'_E - ABP_E = A'B'BA$  by construction. Finally, by the equality between  $A'B'P'_E$  and  $ABP_E$ , the required result that  $B'BP_E P'_E = A'B'BA$  is guaranteed. For a case with these special conditions, the change in expenditures on land values fully measures the benefits of the water/sewerage investment which are not accounted for by direct expenditures on water/sewerage itself, i.e., the increase in price exactly exhausts the increase in consumer surplus.

There is, in practice, no way of determining the magnitude of departures from the necessary conditions without fitting supply/demand models for the housing market. Doing the latter is conceptually plausible, but presents a difficulty that all factors at least as important as 'w/s service would have to be included in the supply/demand model. This requires considerable complication and detail for the model, something which we might not be able to give to it. We choose, consequently, to evaluate the model with different empirical techniques which attach little significance to the econometric structure of the market. This consequently avoids the usual demand/supply analysis' unsuitable use of consumers' surplus as a measure of welfare when real income does not remain constant as prices change. While for small-scale expenditures this is unimportant, it is not for housing expenditures which account for a high proportion of consumers' budgets. With methods which avoid the use of supply/demand analysis, however, we avoid the trouble, because, the statistical analysis gives a direct measure and, in so doing, incorporates the appropriate "income effects."

If we assume that the market looks less perfect for land value benefit measurement than that shown for example in Figure 6.1, then there will not be 100% capitalization. This, of course, is exactly the market feature that makes for an interesting benefit distribution.\* Suppose the demand curve shifts disproportionately over the range of quantity and supply has a finite positive elasticity as shown in Figure 6.2. Analysis of equilibrium land value changes over time would show that values increased by the amount BC. This would be an insufficient amount to measure fully the unpaid-for (in the water/sewerage market) benefits BJPH. In fact, even quantity BE, which would be established were it not for elastic supply, is insufficient to measure the full unpaid-for benefits, falling short by the sum of amounts LGH and JPL. The true price increase measures benefits which fall short of the benefits measured by BE by the amount KLEC and therefore misestimate true benefits by  $KLEC + LGH + JPL$ .\*\* Of these quantities we can believe that BCKJ, the increased value, accrues to the developer and the remainder  $KLEC + LGH + JPL$  accrues to the potential new resident owner.

If we could measure the quantity BE (=JL) and the quantity BC, then most of the distributional implications can be derived. The increase BE measures all of the benefit area but LGH and JPL and increase BC measures

---

\*With 100% capitalization, distribution accrues solely to a single factor - land and to the individuals responsible for development in the first place.

\*\*In fact with recognition that price OC is established over an increased number of houses and certain weighted estimates of the price change on new houses, the actual price increase may misestimate true benefits  $KLEC + LGH + JPL$ .

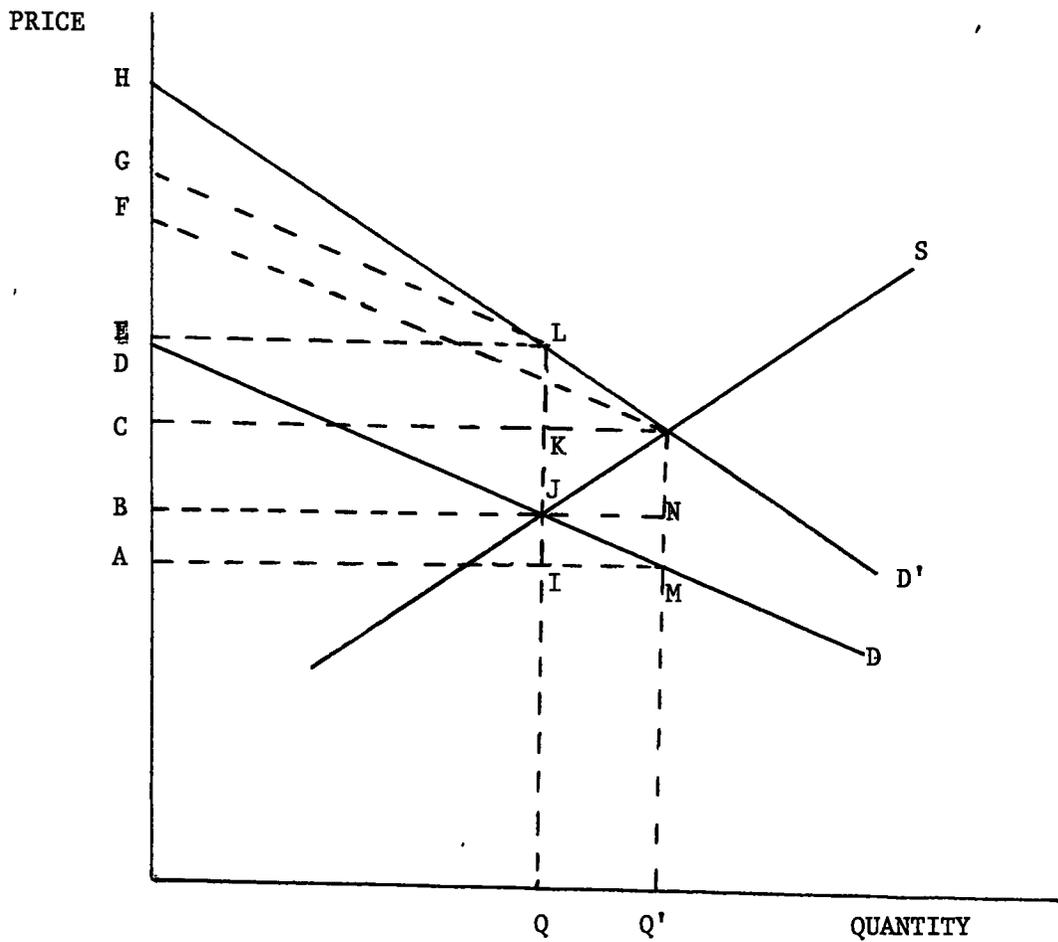


Figure 6.2 THE GENERAL MARKET FOR PROPERTY

all of the same but with the added exception of KLEC. By subtracting the two we can get a measure of KLEC; BE directly estimates BCKJ; with the two we can approximate the distribution by implying that KLEC accrues to the new owner-resident and BCKJ accrues to the developer and still falls within an error of margin of LGH + JPL, being conservative in attributing benefit distribution to the new owner-resident. We cannot increase our efficiency without knowing information about supply and (change in) demand elasticities. Since we believe that the misestimation of distribution which will occur is small if we ignore it and since we wish to avoid the errors in the more complex simultaneous supply/demand housing market, we develop analysis which estimates the values only of BC and BE. We also ignore the difficulty of transforming these price changes per unit into value changes multiplying over quantity and more simply express our estimates on a per unit (per occupant) basis. This implicitly ignores the difficulties inherent in the welfare triangle JPL.

### 6.3 Statistical Modelling

The measurement problems associated with estimating the property value effects of water-sewerage investments are clearly enormous. Most important is the overriding issue of how to separate the effects of the particular investment being studied from the effects of the myriad of other factors which influence land values. The model developed here deals with these problems by using a "control area" approach. Property values in the "project" area are compared with property values in a similar "control" area over a period during which the water-sewerage project in question is built. The object is to estimate the difference

in the increase in property values in the two areas during the period.

It is clearly important that the selected control area should be similar in most relevant respects to the project area, i.e., with respect to housing and population density; income; age, area, and value of property; ethnic mix; and location within the metropolitan area. The control and project areas in the case study undertaken here were chosen on the basis of such similarities with the result that it could be assumed that land values in the control area were the outcome of the same behavioral reactions as those in the project area. This had the effect, for example, of holding constant the influences of important but easily overlooked and difficultly modelled variables as the improvement of bus services or the building of a new plant in the immediate area. Both would have the same effects on property values in the control area as the project area, negating their influences as a distortion to measuring water/sewerage impacts. This leaves us with a clear path to measurement of the w/s divergence which we wish to measure.

While we have rejected the possible use of rental values because of their inapplicability in the current case study, use of assessed values because of the bias implicit in a single officer's (assessor) judgment, use of census tract reported housing values because of bias in self estimation,\* aggregation problems,\*\* the relative largeness of census observations in comparison to the selected project and control areas, and the

---

\*See Kish and Lansing (1954) and also Davis and Wertz (1969) on the conflicting evidence of directional bias.

\*\*Coelen (1973) has earlier made such a criticism of the use of aggregate census data.

essential cross-sectional attitude of census estimates, we are left with property sales as a source of housing market information. Properties, however, sell over irregular intervals with the result that, over a study period of any given number of years, sales value data are available for different properties in different years. To illustrate the problem, assume that sales value data were recorded for N properties in the control and project areas over a period of t years. It would be possible to compute a rate of growth in property value between any two years, for any property which sold between those two years. These rates of growth might be arrayed in the following type of table:

<u>Property Number</u>	<u>Combination of Years</u>					
1	$rog_{12}$	$rog_{13}$	$rog_{1t}$	$rog_{23}$	$rog_{2t}$	$rog_{t-1,t}$
2	$rog_{12}$	$rog_{13}$	$rog_{1t}$	$rog_{23}$	$rog_{2t}$	$rog_{t-1,t}$
3	$rog_{12}$	$rog_{13}$	$rog_{1t}$	$rog_{23}$	$rog_{2t}$	$rog_{t-1,t}$
.						
.						
.						
N	$rog_{12}$	$rog_{13}$	$rog_{1t}$	$rog_{23}$	$rog_{2t}$	$rog_{t-1,t}$

where, for example,  $rog_{12}$  is the compound rate of growth in property value between years 1 and 2, and  $rog_{2t}$ , the rate of growth between year 2 and year t. If the sample could be subdivided into project and control areas (which it can) and if an  $rog_{ij}$  existed for every pair of years, i, j, for

every property (which it doesn't), then estimation would be straight forward, evaluating that relative to the control,  $rog_{ij}$ 's that have  $i$  and  $j$  on differing sides (temporally) of the w/s investment will be higher in the project area. Standard errors for inference testing could be obtained by looking at the relative differences in control and project  $rog_{ij}$ 's when  $i$  and  $j$  were both (temporally) on the same side of the w/s investment, either before or after.

In practice, the fact that all properties do not sell every year complicates the estimation process considerably. It becomes necessary to use those data on sales values which are available to impute values for the missing  $rog_{ij}$ 's, in effect estimating on the basis of existing data on rates of growth in value the average project and control rate of growth indices so as to have information available every year. The comparison between project and control area property value growth rates then proceeds using the imputed indices which we call Bailey, Muth and Nourse (BMN) indices after their original work (1963) which was extended earlier in Coelen (1973). This enables time series analyses. Cross-sectional analysis, of course, is always open to us so long as we wisely sample available observations in any given year.

### 6.3.1. Cross-Sectional Modelling

Lancaster's theory (1966) and the early hedonic work of Grilliches (1961) form the theoretical basis for our work. More directly applied to the environmental area are the early work of Ridker and Henning (1967), Crocker and Anderson (1971) and lately the econometric theory of Rosen (1974). What work we do accomplish is based upon these papers as antecede-

dents and much of the ground that they develop could be restated here, but we assume it implicitly as the perceived body of theory and application, the comments and criticisms of which apply as well here as in the early work. The particular conclusion of the preceding literature which we wish most to highlight here is that a cross-section regression of property characteristics on property values identifies the hedonic demand marginal willingness-to-pay values for each of the included characteristics. Referent to Figure 6.2, this identifies the value BE when carried out with data on property values in a year prior to the project.

Because the data was selected from areas where most of the "macro-market" variables (such as neighborhood aesthetics, locational characteristics relevant to the CBD and other variables which equally affect all properties) were held constant, the cross-section equation was made more simple. The first specification was given as:

$$PV^t = a \text{ SEWWAT}^b \text{ LOTA}^c \text{ STD}^d \text{ AGE}^e \text{ BDR}^f \text{ MASON}^g \text{ ABUT}^h \quad (6-14)$$

with:  $PV^t$  = property value in time t, a constant in any given cross-sectional analysis.

SEWWAT = 1 if no w/s service; 2 if w/s service

LOTA = lot size in acres

SDT =  $e^*$  if split level; 1 if not

AGE = age of structure in years

BDR = number of bedrooms

MASON = e if masonry structure; 1 if not

ABUT = e if further than 800 feet from Pa. turnpike; 1 if not

---

\* e is the number of the base of the natural logs 2.71828...

The variables used in equation (6-14) are most of those frequently used in assessment studies of property value. By eliminating many of the other variables that are important by sampling properties that are similar and that hold those variables constant, we can meet the condition which is the established criterion of the literature, namely, including all variables that are at least of greater or equal importance in determining property values than is water/sewerage service (SEWWAT).<sup>\*</sup> Holding important variables constant in the sample by sampling carefully from control and project areas reduces the probable multicollinearity with which we must deal. Nevertheless the laundry list of variables listed about does produce understandable multicollinearity, especially when, for example, the nexuses between lot size and existence of w/s service and between age and w/s service are revealed as high correlations.

As a consequence of likely multicollinearity, the model was treated as the original work of Ridker and Henning suggests, providing conservative and liberal estimates of the SEWWAT coefficient. Liberal estimates are obtained by regressing SEWWAT on each of the other independent variables, residualizing them,<sup>\*\*</sup> and then regressing SEWWAT and the residuals each on PV as a single multivariate regression. This is equivalent to regressing SEWWAT directly on PV as a bivariate regression. Conservative estimates of the SEWWAT coefficient is obtained by regressing each of the

---

<sup>\*</sup> See Rider and Henning (1967) for the genesis of this criterion.

<sup>\*\*</sup> That is, the residual was constructed for each independent variable as its actual value minus its forecast value conditioned only by SEWWAT.

independent variables but SEWWAT on PV in a single multivariate regression and residualizing PV as a result of this regression. Calling the residual RPV, the residual is regressed on the single independent variable SEWWAT.

The coefficients that are returned are capable of being likened to partial and total derivatives. If we designate the other independent variables (but not SEWWAT) as  $x_i$ ,  $i = 1, \dots, 6$ , then it is clear that the liberal estimate is the total derivative of PV with respect to SEWWAT under the assumption that the covariance between SEWWAT and the  $x_i$  is attributable to SEWWAT. The liberal estimate is interpretable as:

$$\frac{dPV}{dSEWWAT} = \frac{\partial PV}{\partial SEWWAT} + \sum_i \frac{\partial PV}{\partial x_i} \frac{dx_i}{dSEWWAT} \quad (6-15)$$

The conservative estimate on the other hand is the total derivative under the assumption that  $dx_i/dSEWWAT = 0$  for all  $i$  but  $dSEWWAT/dx_i$  are all non-zero attributing all the common covariance of SEWWAT and the  $x_i$  with PV to the  $x_i$  rather than the reverse as above in (6-15). The traditional multivariate regression without any residualizing using the variables described above, of course, provides a coefficient interpretable as  $\partial PV/\partial SEWWAT$ , the true partial.

Finally in the cross-sectional work a nonlinear (even in logs) form that is linearizable was tried on the data to represent the *a priori* hypothesis that the extent to which SEWWAT affects property values depends upon the ability to utilize w/s service for potential latter subdivision. That is, we believed that the impact of SEWWAT, measured by its coefficient, was nonconstant and in fact, a function itself of the size of the lot if that lot was big enough to be subdividable. Consequently, a variable SLOT

was created and was set equal to lot size (LOTA) if  $LOTA \geq 3$  acres and 0 otherwise. This was done on the basis that in the judgment of the assessor in charge of properties in the case study area, at least 3 acres were needed for commercial subdivision. Equation (6-14) was respecified as:

$$PV = aSEWWAT^{b'} + iSLOT^{i'} LOTA^c STD^d AGE^e BDR^f MASON^g ABUT^h \quad (6-16)$$

which upon taking logs and transforming gives a linear equation:

$$PV = a + b' SEWWAT + i' SEWWAT SLOT + c LOTA + d STD + e AGE + f BDR + g MASON + h ABUT \quad (6-17)$$

where variables or parameters in italics are interpreted as natural logs of their relevant counterparts.

### 6.3.2. Time Series Modelling

Use of the BMN model in this study did not follow directly from previous specifications of the technique, BMN (1963) and Coelen (1973). It was selected, however, as a means of identifying, under certain conditions, the actual change in property values that occurs over time, estimating the value BC in Figure 6.2. The use of BMN models for such work has been the practice, for example, of Nourse (1962), Langley (1976) and Arvin (1975). These earlier studies have generally applied the model to areas where the mix of properties exchanged was confined to one general type. However, in the sample for this study, both large and small land tracts as well as housing units were selected for study. It did not seem prudent to assume that these types of properties would have equal property value growth rates or that the provision of off-site sewage and water service would affect each of their growth rates by the same

magnitude. Consequently separate BMN indices were fit to the various homogeneous samples separately.

The initial step in the time-series regression procedure was to create subsamples, one containing properties whose initial transaction involved only land in tracts larger than three acres and one whose initial transaction contained only tract housing. The first subsample was designed to include those properties which had been subdivided or developed during the period or which had the potential for subdivision and/or development. The second sample classification was designed to include those properties which, in effect, were incapable of subdivision.

Given these subsamples, procedures calculating a BMN index were followed with only certain modifications to estimate indices for developing and established residential property. Modifications involved adjusting the observed rate of growth in property values on property  $p$  calculating  ${}^p\text{ROG}_{ij}$  between sales in years  $i$  and  $j$ , based on per acre property values. The  ${}^p\text{ROG}_{ij}^*$  for the developing property subsample was adjusted in a fashion somewhat similar to that used in Coelen (1973) and Nourse (1962). Such adjustments release the control and project values respectively of exogenous influences specific to each of the areas individually but leave those related to the subject intact. In the current case, the study area could be characterized by four property types: (1) large tracts of land (defined to be greater than 9 acres) suitable for farming or specula-

---

\* Only data on those properties selling at least twice in the sample period was collected.

tion, (2) smaller tracts of land (defined to be greater than 4 acres but less than 9 acres) suitable for cluster development, (3) small sets of sites (defined as less than 4 acres but capable of multiunit development), and (4) individual residential housing units. Definitions were based on *a priori* information about development that resulted from discussions with local public officials, realtors, county planners, contractors and area residents.

The rate of growth in property values between any two periods is explained in part by its transition among property types. Consequently, in order to isolate these transitional influences from the rate of growth in properties, the following adjustment procedure was followed in calculating the project and control area indices:

$${}_p \text{ROG}_{ij} = a + b {}_p \text{BLT} + c {}_p \text{RFD} + d {}_p \text{SUB} \quad (6-17)$$

where:

$i < j$ , and  ${}_p \text{ROG}_{ij} = \left( \frac{{}_p \text{PV}_j}{{}_p \text{PV}_i} \right)^{1/j-i} - 1$  where  ${}_p \text{PV}_j$  is the value of property  $p$  year  $j$ ;  ${}_p \text{PV}_i$ , year  $i$ .

${}_p \text{BLT} = 1$ , if a structure had been added to property  $p$  between  $i$  and  $j$ , and 0 otherwise;

${}_p \text{RFD} = 1$  if the property was subdivided so that it was greater than 9 acres in  $i$  but less than 9 acres in  $j$ , and 0 otherwise;

${}_p \text{SUB} = 1$ , if the property was subdivided so that it was less than 4 acres in year  $i$ , and 0 otherwise.

Given the coefficients in (6-17), the rate of growth was residualized which corrected rates of growth only when subdivision or building had occurred. This is a logical procedure to follow because we would ultimately like to develop an estimate for the property value increase following w/s service for a standard property and certainly do not wish to confuse such value changes with changes in the stage of development of the property.

The  ${}^p\text{ROG}_{ij}$  for the established (developed) property subsample was adjusted in an analogous fashion, but for these properties, the size of lot is much less likely to have changed between  $i$  and  $j$ . What has been found in previous studies is that the rate of growth is heavily influenced by its initial value and so as to standardize for this factor the following regression:

$${}^p\text{ROG}_{ij} = a + b \text{PV}_i \quad (6-18)$$

and residualization:

$$\hat{{}^p\text{ROG}}_{ij} = {}^p\text{ROG}_{ij} - a - b \text{PV}_i \quad (6-19)$$

were undertaken.

In order to develop a general index, following the modification by Coelen (1973) of BMN, the regressions were run for the subsamples separately on the project area data:

$$(j-i)\log_e (1 + \hat{{}^p\text{ROG}}_{ij}) = \sum_{\alpha=1}^{T-1} \text{rog}'_{\alpha} \delta_{\alpha} + \log_e \epsilon_{ij} \quad (6-20a)$$

and on the control area data:

$$(j-i)\log_e (1 + \hat{{}^p\text{ROG}}_{ij}) = \sum_{\alpha=1}^{T-1} \text{rog}'_{\alpha} \delta_{\alpha} + \log_e v_{ij} \quad (6-20b)$$

where  $\text{rog}_\alpha$  is the coefficient which estimates the best fit for an index of individual year rates of growth for the subject and control area respectively;  $\epsilon_{ij}$  and  $v_{ij}$  are the error terms; and  $\delta_\alpha = 1$  if  $i \leq \alpha < j$  and 0 otherwise.

In effect, this step regresses each of the sets of  $\hat{\text{ROG}}_{ij}$ 's on a set of dummies representing the years for which the  $i$  and  $j$  are relevant; that is, between years  $i$  and  $j$ . This effectively constructs a weighted average of the raw data and estimates the log of the individual year rates of growth as:

$$\log \text{rog}_\alpha = \sum_{\Pi=i-1}^{i+1} \psi_\pi \sum_{j=\pi+1}^T \sum_{\alpha=1}^{\Pi} (j-\alpha) \log_e (1+\text{ROG}_{\alpha j}) \quad (6-21)$$

where:  $\psi_\pi = (-1)^{T-1}/T$  for  $\Pi = i-1$  and  $\Pi = i+1$

except for  $i=1$  when  $\psi_0 = 0$

and for  $i = T-1$  when  $\psi_T = 0$

$\psi_\pi = 2/T$  for  $\Pi = i$

As shown earlier (Coelen, 1973), it is also quite clear that certain of the coefficients are based upon more data than others. For example, it is evident in (6-20) that  $\text{rog}_1$  is based upon the weighted average of  $2(T-2) + T-1$  terms. The estimate of  $\text{rog}_2$  is based upon  $3(T-3) + 2(T-2) + T-1$  terms. From this it is easily generalized that  $\text{rog}_\alpha$  is based upon  $\alpha + 1(T-(\alpha+1)) + \alpha(T-\alpha) + \alpha - 1(T-(\alpha-1)) = 3\alpha(T-\alpha) + 2$  terms in its calculation. By using a regression approach we obtain a best linear weighted index which minimizes the variance of the errors in explaining any observed rates of growth between years  $i$  and  $j$  by estimated rates of

growth for each year between  $i$  and  $j-1$ .\*

Following the construction of the annual series on rates of growth by property subsample in the control and project area, the values,  $rog_{\alpha}$ ,  $rog'_{\alpha}$  are transformed into property value indices for each of the  $T$  years, for the project and control areas respectively. This is done by calculating for each of the areas respectively:

project:

$$proj\ Index_{\alpha} = 100 \prod_{\gamma=1}^{\alpha-1} e^{rog_{\gamma}} \quad (6-22a)$$

control:

$$con\ Index_{\alpha} = 100 \prod_{\gamma=1}^{\alpha-1} e^{rog'_{\gamma}} \quad (6-22b)$$

where the value of the index in year one is taken to be 100.

In order to evaluate the impact of water/sewerage on property values, temporally, the control influences, representing the "macro market" variables was subtracted from the project index and the result was regressed on a time dummy to show the influence at the time of the project:

$$proj\ Index_{\alpha} - con\ Index_{\alpha} = M + N \delta_{project} \quad (6-23)$$

where  $\delta_{project} = 1$  if  $\alpha \geq \alpha^*$ , the impact period, or implementation period, of the water sewerage investment and  $\delta_{project} = 0$  otherwise. This is equivalent to analysis of variance.

---

\*Proof of this and the econometric properties of the model are available in Coelen (1973).

## 6.4 The Distinction Between Time Series and Cross-Sectional Analysis

With two methodologically distinct measures of the difference in values between serviced and unserviced areas--the time series and the cross-section, we should be careful to note that they do depict differing substantive concepts. We have already suggested by referring to their usage in the literature that the cross-sectional methods generally measure the point in time willingness-to-pay price differential between serviced and unserviced properties. In a similar way, it has been implied that the time series measures actual change in equilibrium values. A more careful statement of this distinction is in order.

### 6.4.1. Differences Between the Cross-Sectional and a Pure Time Series Measure\*

Envision a tripartite city with one part which is not currently serviced with  $w/s$  and which has never been serviced, one part which has been serviced for a long time, and one part which was previously unserved but which has recently been serviced. Denote the never serviced area as J, the always serviced area as K, and the recently serviced area as I. The time period,  $t_0$  is unambiguously before and  $T_0$ , unambiguously after anticipation of and adjustment to the servicing of area I. In other words,  $t_0$  can be taken as the last period of long run equilibrium before the servicing and  $T_0$ , the first period of long run equilibrium after servicing. While serviced and unserviced properties are highly substitutable, consider them to be in different markets. Properties in area I are assumed initially ( $t_0$ ) to make up part of the market of homogeneous properties lacking servicing. This market also includes all the

---

\*This work has been adopted from the previously published material in Coelen and Carroll (forthcoming).

properties of area J. As area I becomes serviced, properties in I move from the unserviced market (i.e., the J market) and by period  $T_0$  are homogeneous units in the K market. Assuming reasonable competition in J and K markets, housing prices in those markets (denoted by subscripts) are equalized in the respective periods so that:

$$I^P_{t_0} = J^P_{t_0} \text{ and } I^P_{T_0} = K^P_{T_0} \quad (6-24)$$

These prices indicate a measure of the total hedonic value of attributes associated with respective property types. In this simple case an equilibrium adjustment is assumed in markets for products which differ only by the flow of benefits associated with w/s service. As such, two hedonic values can be calculated for such benefits in equilibrium periods  $t_0$  and  $T_0$ :

$$H_{t_0} = K^P_{t_0} - J^P_{t_0} = K^P_{t_0} - I^P_{t_0} \quad (6-25)$$

and

$$H_{T_0} = K^P_{T_0} - J^P_{T_0} = I^P_{T_0} - J^P_{T_0} \quad (6-26)$$

The ambiguity inherent in the existence of two measures arises because the hedonic, cross-sectional measures can be constructed at many points in time.

The time series measurement of the effect of servicing on properties in area I is defined as:

$$TS' = I^P_{T_0} - I^P_{t_0} = K^P_{T_0} - J^P_{t_0} \quad (6-27)$$

No ambiguity exists in this definition.

Using the relationships developed in (6-24) through (6-27), it is clear that the measures may not be identical. Adding and subtracting equal quantities on the right hand side of (6-27):

$$TS' = K^P_{T_0} - (J^P_{T_0} - J^P_{T_0}) - J^P_{t_0} + (K^P_{t_0} - K^P_{t_0}),$$

and substituting from equations (6-25) and (6-26)

$$TS' = H_{T_0} + J^P_{T_0} + H_{t_0} - K^P_{t_0}$$

so that  $TS' = H_{T_0}$  if and only if  $H_{t_0} = K^P_{t_0} - J^P_{T_0}$ . This can occur only

if there is no price reaction in the unserviced area from the servicing area I (i.e.,  $J^P_{T_0} = J^P_{t_0}$ ). Similarly,  $TS' = H_{t_0}$  if and only if  $H_{T_0} =$

$K^P_{T_0}$  which would require no reaction of the K properties to the servicing of area I so that  $K^P_{t_0} = K^P_{T_0}$ .

For any sizeable impact of a w/s service program, the conditions

$K^P_{t_0} = K^P_{T_0}$  and  $J^P_{t_0} = J^P_{T_0}$  would not be expected to hold because of the

market reactions of transferring I-area properties out of the J market and into the K market.

These notions may be extended into a structural model of the property market. The demand relations are written as functions of all relevant commodity prices:

$$J^Q_t = f_J(J^P_t, K^P_t, X^P_o) \quad (6-28)$$

and

$$K^Q_t = f_K(K^P_t, J^P_t, X^P_o) \quad (6-29)$$

where  $K^D_t$  and  $J^D_t$  are the demand quantities in the serviced and un-serviced markets respectively and  $X^P_o$  is the price of some composite good. The long run supply curves are written simply as functions of the prices in respective housing markets and an exogenous price of building materials:

$$J^S_t + I^Q_o - I^Q_t = \xi_J(J^P_t, y^P_o) \quad (6-30)$$

$$K^S_t + \mu_I I^Q_t = \xi_K(K^P_t, y^P_o) \quad (6-31)$$

where  $K^S_t$  and  $J^S_t$  are the quantities of properties in the K and J areas supplied to the K and J markets respectively;  $I^Q_o$  is the initial fixed quantity of property in area I supplied to the J market;  $I^Q_t$  are the additional properties in the K market which had each been subdivided, on average, into  $\mu_I$  properties from the original  $I^Q_o$  properties because of the relaxed zoning conditions that accompany w/s investment; and  $y^P_o$  is the price of a composite building supply good. Subdivision by a factor such as  $\mu$  is usually the consequence of zoning change. The short run supply functions need not be defined to locate the initial and final (post-servicing) equilibria since these are meant as long run equilibria. However, the short run functions are used implicitly, for example, by the inclusion of the terms  $(-I^Q_t)$  and  $(+\mu_I I^Q_t)$  in equations (6-30) and (6-31) respectively. The model is completed by adding the equilibrium equations:

$$J^D_t = J^S_t + I^Q_o - I^Q_t, \text{ and} \quad (6-32)$$

$$K^D_t = K^S_t + \mu_I I^Q_t \quad (6-33)$$

Application of the model prior to the implementation of servicing to any of the given set of properties in area I is carried out by simply assuming  $I^Q_t = 0$ . With the introduction of service in area I,  $I^Q_t$  is greater than zero, entering exogenously into the simultaneous equation system (6-28) through (6-33) to reflect the number of properties adding w/s capacity.

From such a model it is easy, at least conceptually, to derive the reduced forms for the endogenous variables  $J^Q_t = J^{Q^S}_t + I^{Q_0} - I^Q_t = J^{Q^D}_t$ ,  $K^Q_t = K^{Q^S}_t + \mu_I^Q_t = K^{Q^D}_t$ ,  $K^P_t$  and  $J^P_t$ . The reduced forms then yield the important derivatives,  $d_{J^Q_t/d_I^Q_t}$ ,  $d_{K^Q_t/d_I^Q_t}$ ,  $d_{K^P_t/d_I^Q_t}$ , and  $d_{J^P_t/d_I^Q_t}$ , which can be used to construct the measures specified in (6-24) through (6-27) above:

$$H_{t_0} = K^P_{t_0} - J^P_{t_0},$$

$$H_{T_0} = K^P_{T_0} - J^P_{T_0} = H_{t_0} + \left[ \frac{d_{K^P_t}}{d_I^Q_t} - \frac{d_{J^P_t}}{d_I^Q_t} \right] I^Q_t \text{ and}$$

$$TS' = K^P_{T_0} - J^P_{t_0} = K^P_{t_0} + \frac{d_{K^P_t}}{d_I^Q_t} I^Q_t - J^P_{t_0} = H_{t_0} + \frac{d_{K^P_t}}{d_I^Q_t} I^Q_t$$

This structural model demonstrates the conceptual differences both between cross-sectional and time series estimates and between intertemporal cross-section estimates. In the framework of implementing a simultaneous equation methodology (equations (6-28 through 6-33)), there is no *a priori* expectation about possible interrelationships except on a case by case basis, where the forces operating in affected markets may be evaluated to yield expectations about such relationships.

We are left with the problem of interpreting these various measures and of knowing which to select so as to provide the right kind of information. The solution can be developed from the old debate found in the papers of Ridker and Henning (1967), Freeman (1971) and Edel (1971) over Ridker and Henning's erroneous generalization that their cross-sectional regression coefficient for pollution (on housing values) multiplied by the number of affected properties gives an expected response to pollution abatement in the housing market. These arguments suggest that cross-sectional work is partial equilibrium modelling incapable of obtaining general equilibrium results of the market reaction to more than a marginal change of some environmental variable, in this case, w/s service.

There are really two environmental changes which are troublesome--changing the variable more than marginally at a single observation (property, census tract, etc.) and changing the variable marginally at more than a marginal observation. It is a solution of the second difficulty that Edel's comment (1971, pp. 10-11) is applicable in suggesting that Ridker and Henning's erroneous calculations provide accurate welfare information. From this debate, without proof, we offer the following suggestions:

1. For the case of a marginal change in the environment at a marginal observation, the cross-sectional measure correctly states both the appropriate welfare standard of willingness-to-pay for the environmental change as it is capitalized into the land (property) market and the actual land value reaction that would be observed to result from the change.

2. For the case of a marginal change in the environment, at more properties than just the marginal property, as would be the case for w/s ser-

vice under certain conditions, the cross-section result correctly states the average willingness-to-pay but is unlikely to forecast accurately the actual land value change. This is related to open city-closed city models of Polinsky and Shavell (1975) and the suggestions of Edel (1971).

3. For the case of a more than marginal change in the environment confined to a marginal property, the cross-section result is likely to measure neither the land value reaction nor the welfare change correctly because of less than perfectly elastic demands for most environmental commodities. However, joint use of cross-sectional measures taken before and after the environmental change may give information that averaged together approximates the average marginal willingness-to-pay over the relevant range of environmental conditions. This average times the number of units of change may approximate the property market value changes.

4. For non-marginal changes both at observations (properties) and of environmental conditions, in this case, the provision of w/s and its related zoning relaxation throughout a market area, the cross-sectional measures are likely only to approximate the welfare measures and not the actual market changes, and then only by multiplying the average of the two temporal cross-section results by the number of units affected by the change in environmental conditions.

While the cross-sectional measures under all four conditions yield very useful information, it is clear that they fall short most when asked to give full information in cases of simultaneous changes at many properties. It is then that they fail to give information on expected actual

market changes. It is especially in these cases that time series measures are most powerful. The time series method directly evaluates the impact of actual environmental changes already implemented in the economic world and therefore the method compares pre- and post-event prices to determine the market reaction. The shortcoming of the time series approach as a method is its ability to accomplish only this result, failing (except in the case of marginal changes) to measure any welfare standards, alone only measuring the extent people are actually forced to pay.

#### 6.4.2. Differences Between the Pure Time Series Measure and a BMN Measure

The time series measure,  $TS' = I_{T_0}^P - I_{t_0}^P$ , developed in section 6.4.1 does not relate directly to that measured by the BMN indexing technique when it is coupled with a control area methodology. Since the control area methodology subtracts the control index from the project index before estimating the increase in values in (6-23) we must account for the additional influence of the control. If the control is truly a control then it is selected far enough away from the project service area, spatially, that the project and control areas are independent--neither with the values of the control change because of initial changes in project area values (resulting from the w/s investment) nor will in turn, the project values change because of any secondary value changes in the control. Such an independent control selection nevertheless is not an unmixed blessing. When the control is chosen far from the project area, then it acts less like a control, more probably affected by influences

unimportant to the project area and more probably unaffected by variables important to the project area.

If, on the other hand, the control is necessarily close to the project area, then it will have picked up some of the secondary impacts of the project, finding that values there equilibrate with the changing project area values. This latter force is a necessary consequence of the two areas being highly substitutable.

We can analyze the prospects by defining a new time series measure, subject to the control, and by assuming that the control is indirectly affected by the project. When we do so it becomes apparent that an ambiguity is introduced into the time series definition just as there was into the hedonic measure earlier. Define a time series measure based on a control of properties always without service as:

$$TS^C = I^P_{T_0} - I^P_{t_0} - (J^P_{T_0} - J^P_{t_0}) \quad (6-34)$$

and on a control of properties always with service as:

$$TS^P = I^P_{T_0} - I^P_{t_0} - (K^P_{T_0} - K^P_{t_0}) \quad (6-35)$$

By substitution for  $I^P_{T_0}$  and  $I^P_{t_0}$ , these two control area time series

measures are shown to be nothing other than an alternate measurement technique for hedonic indices, with:

$$TS^C = H_{T_0} \quad \text{and} \quad TS^P = H_{t_0} \quad (6-36)$$

This implies, of course, that the control time series measures do not measure the actual change in values but rather the hypothetical change

which would occur in a single period without supply adjustment. Since we can go further and express the alternate time series measures as:

$$TS^c = TS' - (J^P_{T_0} - J^P_{t_0}) \text{ and} \quad (6-37)$$

$$TS^P = TS' - (K^P_{T_0} - K^P_{t_0}) \quad (6-38)$$

then it becomes clear that one or the other is likely to more closely match with our ideal measure,  $TS'$ . The difference depends simply on which of the two control areas is more likely to be affected by the project, and those conditions are the same as these given on page 147.

This, of course, implies that we cannot identify a time series measure,  $TS'$ , without having to assume that certain conditions hold. However, the time series measure is important because it gives us another independent check on  $H_{T_0}$  or  $H_{t_0}$ , empirically. Given the skepticism apparent in the literature (Lave (1972)), about the ability to identify land value increments and the sensitivity of the cross-sectional results to specification, an independent estimate is important information.

## 6.5 Other Considerations

Before outlining the details of the case study selected, some specific complications are discussed.

### 6.5.1 The Problem of Anticipation and Adjustment

Frequently, property values rise in anticipation of a promised improvement. When this happens in a project area, the increase in property values after the investment will tend to understate the true benefits. Ideally, one should take account of this, but it would, of

course, be complicated, particularly if the control area is adjacent, has never been serviced, and properties are also increasing in value in expectation that project area improvements will be extended to them.

The same difficulty can arise from a 'slow response of adjustment to a new project or because of the site improvements that might accompany a new project. A property served by a public water supply or sewerage system for the first time may only be able to utilize these services fully, if improvements, such as the addition of a bathroom, are added, or what is likely in this country, the addition of a swimming pool. The benefits of these improvements will be capitalized and reflected in land values. While attributable to the project, the resultant increases will overstate net benefits, if a correction is not made for the costs of the improvements. Since it can be assumed that competition in the home improvement industry is fairly keen, subtraction of the capitalized value of improvement costs from the property value increment would be sufficient adjustment.

We deal with the problem in the cross-sectional method by selecting dates for sampling that are far enough removed from the project's implementation that we minimize the difficulty. For the time series, two methods are adopted. One is to denote the effective beginning date of the w/s project influence by a series of alternative dates, judging the results for their sensitivity to the choice of dates. The second is to suggest explicitly that instead of model (6-23) holding exactly that with recognition of expectations and adaptations, it should be reformulated as:

$$\text{proj Index}_\alpha - \text{con Index}_\alpha = M + N \delta_{\text{project}_\alpha}^* \quad (6-39a)$$

$$\delta_{\text{proj}_\alpha}^* - \delta_{\text{project}_{\alpha-1}}^* = \theta (\delta_{\text{project}_\alpha} - \delta_{\text{project}_{\alpha-1}}) \quad (6-39b)$$

The model is fit by recognizing that

$$\delta_{\text{project}_\alpha}^* = \theta \sum_{\mu=0}^{\infty} (1-\theta)^\mu \delta_{\text{project}_{\alpha-\mu}}$$

from (6-39b) and substituting into (6-39a) logging and subtracting as in the Koyck lag technique, we would fit:

$$\text{proj Index}_\alpha - \text{con Index}_\alpha = M\theta + N\theta \delta_{\text{project}_\alpha} + (1-\theta) \left[ \text{proj Index}_{\alpha-1} - \text{con Index}_{\alpha-1} \right] \quad (6-40)$$

### 6.5.2. Property Taxes

In most types of local taxation systems, the impact of the improvements will raise the property tax base. That is, the increment in property values will itself be subject to a tax. Consequently, if land values would have risen by \$X in the absence of a tax, they will rise by something less than \$X in the presence of a tax. It can be said, roughly, that the total benefit of an improvement should be achieved by the addition of the increase in property values to the additional tax liability. Problems of standardization arise where different areas are subject to different tax systems or levels. However, since the existence of such an effect depends upon the degree to which the assessor recognizes

effects of w/s on property values, we do not so adjust.

### 6.5.3. Externalities

"External" effects arise where there is a divergence between the private and social costs and benefits of a project. In the present context, problems may arise in that the supply of water or sewerage facilities to property X may be to the advantage of property Y, but potential purchasers of X would not take this into account in deciding how much they are willing to pay for the property. Externalities arise where the health of people living in areas adjacent to the project area improves as a result of the improvement in the health of project area residents, or where aesthetic nuisances are prevented from spreading to other areas. To the extent that these effects are associated with water and sewerage investments, use of the technique employed here will tend to underestimate benefits. Note, however, that externalities within the project area should be accounted for by use of property value enhancement as a measure of benefits.

The presence of externalities creates a problem in selecting a control area. Since the control and project areas should be as similar as possible, there are grounds for selecting contiguous areas. However, since the control area should be free of project-related externalities, there is a case for choosing more distant properties for this purpose. The resultant choice of a control area must therefore, compromise between the alternatives. Any choice may be criticized on the grounds either that it is not similar enough to the project area or that it is subject to some externalities.

## 6.6 Selection of the Case Study

The data sets for property value studies, particularly time-series studies, require extensive data collection and the methodologies of both general approaches have several complicating statistical problems. For a time-series methodology using a Bailey, Muth and Nourse (1963) technique, subject and control sites must be selected so that they generate enough repeat sales on enough different properties to yield significant results. Dobson (1970) and Nourse (1962) estimate this number to be around 1,000 properties. Further, the data collection is complicated because the control and subject areas must be reasonably similar in all respects but the one exogenous force whose impact is to be measured. Using such areas for cross-sectional analysis, however, has one advantage. It alleviates some of the multicollinearity which inevitably accompanies property value explanation. This is because proper selection of project and control areas eliminates the need to include certain types of explanatory variables in the property value estimation equation.

Three areas were originally under consideration as study sites: (1) Mercer County, New Jersey, (2) York County, Pennsylvania, and (3) Montgomery County, Pennsylvania. Although all three sites appeared to generate the types of properties necessary for the empirical testing, Montgomery County was selected since it appeared to provide the best fit between control and project areas while meeting data requirements. In addition, it developed that a significant amount of data was already available for the county in machine readable form. A listing of these data is shown in Appendix A. The Montgomery County project of interest

was implemented in the period 1966-1970.\*

The estimation procedures associated with the empirical tests suggested data acquisition from three distinct locations in the county: (1) one which had received access to offsite service in the past five to eight years, (2) one which had never had access to off-site service, and (3) one which had access to it throughout the study period. The north central part of Montgomery County provided such places. These are shown in Figure 6.3. All are in the commutation shed of Philadelphia and within three to five miles of an interchange for the Northeast Extension of the Pennsylvania Turnpike, a main access route to the central city. As shown in Tables 1 through 6 of Appendix B, these areas are relatively similar in terms of various socio-economic characteristics, given the county median values and ranges for these characteristics.

Data collection involved the title search of Montgomery County deeds for over 1,000 properties from the period 1950 to 1975. The result of this effort was a data set of 250 properties exchanged at least twice during the study period under valid market conditions. Collection procedures included listing the data, price and location of a sale; determining the location of deeds for sales of all previous sales on that same property within the study period; and verifying that the deed represented a valid or "arms length" transaction.\*\* The latter was a crucial point

---

\*The minutes of the Board of Supervisors for Towamencin Township (the final approving authority) show discussions of the sewage and water extension project during 1966. Yet, it was not until April, 1967 that the contacts for the initial pumping station and interceptor were actually let and it was not until 1970 that the entire extension project was completed.

\*\* See Downing and Jansma (1970) for a description of these criteria.

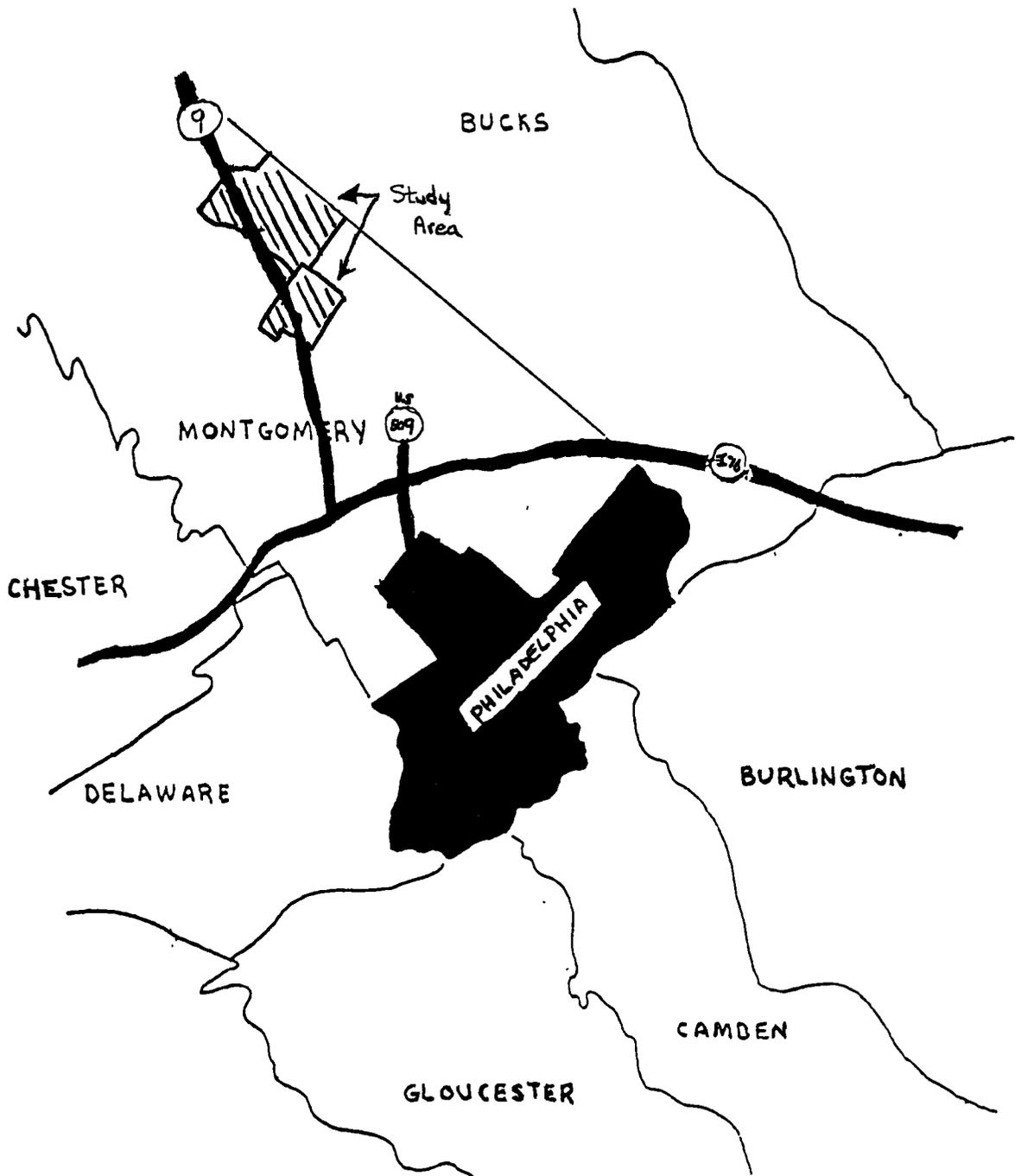


Figure 6.3  
THE STUDY AREA

since many property exchanges occurred between members of the same family or involved the settlement of a will or some other circumstances which did not represent the valid interaction between buyer and seller. To include such sales could have markedly biased results.

#### 6.6.1. Selecting the Time Period for Analysis

In order to make comparisons between cross-sectional and time-series estimates which are in line with the theoretical notions developed in this chapter, it was necessary to apply the cross-sectional regression analysis both before and after the incidence of the sewerage and water project. The time periods selected should reflect pre- and post-project equilibrium conditions in the study area. The periods should also have as large and heterogeneous a sample as possible.

The availability of sample properties for a cross-section analysis from the Montgomery case study is represented in Table 6-1. Since the project was implemented during the period 1966-1970, the periods 1956-57 and 1975 were selected for cross-sectional analysis. Due, however, to limitations of time periods for which property transactions of the subsamples in project and control areas were available, the time series indices had to be calculated over periods of differing lengths and sometimes assumptions of equal annual rates of growth for two or more consecutive years had to be made.\* For developing property, the index

---

\*The econometrics for this procedure is shown in Coelen (1973). It is also shown there that not more than  $(N-1)$  possible annual rates of growth are calculated from a single property that has sold  $N$  times so as not to introduce bias in the non-independence of the error terms:

Table 6-1  
Sample Sizes by Property Types

YEAR	HOUSING SALES		SMALL LOT SALES		LARGE LOT SALES	
	SERVICED No.	UNSERVICED No.	SERVICED No.	UNSERVICED No.	SERVICED No.	UNSERVICED No.
52				2		2
53		1		2		
54					1	1
55	1	2		4	2	
56	12			2		1
57	5	2	1	3	2	
58	4	1			1	
59	10	1		3		1
60	5	5		2		1
61	2			2		
62	2	1		2		2
63	2	1		1		2
64	1	3		3		1
65	2	1		2		2
66	4	2	1	1		7
67	4	2		4		3
68	4	1		1	1	5
69	6	4		6		4
70	6	5	7	4	3	
71	23	6	4	6	4	1
72	24	7	2	3	2	2
73	56	14	2	3		4
74	47	22		6		
75	33	10		3		1

was calculated for the period 1954 through 1974. The index for developed housing was calculated for the period 1963 to 1974.

## 6.7 Results

### 6.7.1. Cross-Sectional Studies

The results of the cross-sectional models are reported for 1975 in Table 6-2 and for 1956-57 in Table 6-3. In each table, the traditional multivariate regression is reported in column 1. The liberal estimate of the SEWWAT exponent is reported in column 2. The conservative estimate is reported in column 3. The estimate that includes a non-constant SEWWAT variable exponent ( $= b' + i \text{ SLOT}$ ) is shown in column 4.

In all cases, the elasticity of property value with respect to SEWWAT is positive and often significant. The liberal estimate is by far the strongest of those in columns 1-3. The conservative estimate is the weakest in those same columns. Since it is difficult to interpret what each of the estimates implies in terms of dollar values, these elasticities are converted into dollar changes in property and land values that would occur as the value of SEWWAT changes from 1 to 2. This is taken from the values forecast by the various equations for the relevant data (land or house and land) and is reported in the last two rows of each table. "Land" properties are defined (arbitrarily) as a 6 acre lot without house more than 800 feet from the Pennsylvania Turnpike. "House" properties are defined as 2 years old, 4 bedroom, non-masonry, split level houses, on a 22,000 square foot lot more than 800 feet from the Pennsylvania Turnpike.

Although column (4) equations in Tables 6-2 and 6-3 appear to perform

TABLE 6-2

Alternate Estimation Equations  
for Property Values in the Study Area, 1975

Equation Number	(1)	(2)	(3)	(4)
<i>Dependent Variable</i>	PV	PV	RPV	PV
<i>Constant</i>	9.37792* (51.2835)	10.336* (95.7629)	-0.112356 (-1.10290)	9.32555 (51.3076)
<i>SEWWAT</i>	0.127821 (1.50009)	0.257471* (4.20436)*	0.066017 (1.14216)	0.113628 (1.35540)
<i>SEWWAT</i> • <i>SLOT</i>				0.0674779* (1.64905)
<i>LOTA</i>	0.170549* (3.06013)	0.170547* (3.06013)		0.105798 (1.57422)
<i>STD</i>	0.180460* (2.32739)	0.180459* (2.32739)		0.237019* (2.84624)
<i>AGE</i>	0.0149284 (0.0360255)	0.001494* (0.036025)		-0.001109 (0.02732)
<i>BDR</i>	.628150* (4.84440)	.628150* (4.84440)		.694318* (4.73164)
<i>MASON</i>	-0.099048 (-0.786286)	-0.099048 (-0.786286)		-0.119235 (-0.96244)
<i>ABUT</i>	0.183378* (1.71606)			(1.87512)
$R^2$	.8027	.8027		.8153
Land: Value	\$3,091.43	\$19,045.93	\$1,784.91	\$17,738.11
House: Value	\$5,550.69	\$34,198.53	\$3,858.27	\$ 4,532.85
n = 47				

\* Significant at the 90% level.

t values in parentiesis below coefficient estimates.

TABLE 6-3

Alternate Estimation Equations  
for Property Values in the Study Area, 1956-1957

Equation Number	(1)	(2)	(3)	(4)
<i>Dependent Variable</i>	PV	PV	RPV	PV
<i>Constant</i>	7.7260 (49.4997)	8.37668 (74.4394)	-0.111759 (-1.05078)	7.74264 (50.3141)
<i>SEWWAT</i>	.52200 (2.14639)	1.4151* (8.57330)	0.156465 (1.24332)	0.229425 (7.00437)
<i>SEWWAT</i> · <i>SLOT</i>				0.091499 (1.30638)
<i>LOTA</i>	.858389* (11.4313)	.858390* (11.4313)		.789392* (8.69838)
<i>STD</i>	.404923 (0.99344)	.404917 (0.99344)		.229792 (0.543992)
<i>AGE</i>	-0.345012* (-2.29346)	-0.345012* (-2.29346)		-0.360137* (-2.42850)
<i>BDR</i>	1.40367* (3.42296)	1.40367* (3.42296)		1.64864* (3.70893)
<i>MASON</i>	0.465590 (0.227527)	0.465590 (0.227527)		0.0460224 (0.228833)
<i>YR</i>	0.250307 (1.47117)	0.250307 (1.47117)		0.230698 (1.37414)
$R^2$	.9256	.9256	.0561	.9318
Land: Value	\$12,175.27	\$134,911.00	\$2,372.39	\$24,271.02
House: Value	\$ 9,465.98	\$104,932.89	\$7,241.28	\$ 4,132.53
n = 28				

\* Significant at 95% level

t values in parenthesis below coefficient estimates

slightly better than the other primary equations (1) and that we would have to interpret (4) as having the same multicollinearity problems that equations (2) and (3) point out relevant to equations (1), equation (4) is selected for emphasis primarily because of *a priori* belief in its better specification. Specifically equations (4) are capable of suggesting that percentage responses to service extension differ with lot size and this is as we would believe *a priori*.

For the 1975 sample, equation (4) indicating an increase in value of \$17,738 for a six acre subdividable lot is consistent with the data we can independently generate. Housing with off-site service were generally placed on 1/4 to 3/4 acre lots. Housing with on-site service required 1 to 1-1/2 acre lots. The use of off-site service would generate between 2 and 20 more lots than on-site service. Accounting for roads, parks and other non-salable property our review of the development plans in Montgomery County showed that when properties were held to 3/4 acre off-site versus 1-1/2 acre on-site service tracts, in fact often 3 more lots were generated with off-site service than with on-site service. Since small acreage plots (3/4 to 1-1/2 acres) sold at equivalent per acre prices and since we estimate that the 1975 going price for a 3/4 acre lot was \$12,000, this implies increased value on a six acre serviced plot to be \$36,000. We expect that the discrepancy between \$17,738 and the \$36,000 can be accounted for by the necessary legal, surveying, transactions, and public utility costs (road, park, in fact sewer construction) per six acre plot. The 1956-57 sample values are interpreted similarly. The use of cross-sectional analysis for estimation of willingness-to-pay then

permits us to escape from the calculations of the many costs (legal, etc.) that partially determine willingness-to-pay off-site sewerage at any point in time.

#### 6.7.2. Time Series Results

The index values calculated for the project and control areas of the developing property subsample and the residential, already developed property subsample (see equations 6-20 and 6-22) are shown in Tables 6-5 and 6-6. In addition, Tables 6-4 a and b report the regression results for the residualizing procedures that were used prior to indexing (equations 6-17 and 6-18). Tables 6-7 a and b give the statistical estimate (equation 6-23) of the impact of w/s service on developing and developed property subsamples. Because of the difficulty of establishing a definite time when the project was implemented, Tables 6-7 give results which alternately assume project implementation dates of 1968, 1969, and 1970. Table 6-8 presents the alternate information on an adjustment model (equation 6-40) assuming the project was generally known around 1966.\*

As expected, *a priori*, the impact of extension on developing property,  $\hat{N}$ , is positive and significant. Looking at Table 6-7a, the range of values of  $\hat{N}$  is small as we change the estimated impact years between 1968 and 1970. This implies that capitalization was relatively quick following the implementation of the project. The rising pattern of this coefficient indicates a positive adjustment to the service, and would

---

\* See footnote, page 159. The equation however, is auto-correlated and containing a lagged dependent variable, the adjustment procedure of Cooper (1972) was used.

TABLE 6-4a

Developing Property Value Indices  
Regression Adjustment Coefficients  
For the Project and Control Areas

Variable	Project Area	Control Area
	Coefficient (t-score)	Coefficient (t-score)
BLT	1.41613 (14.84309)	1.62575 (13.08728)
RFD	1.28144 (8.53529)	-0.07196 (-0.27146)
SUB	-0.38553 (-2.56875)	0.36272 (1.34425)
No. of Observations	104	184

TABLE 6-4b

Developed Property Value Index  
Regression Adjustment Coefficient  
for the Project and Control Areas.

Variable	Project Area	Control Area
	Coefficient (t-score)	Coefficient (t-score)
PV <sub>i</sub>	0.17008 (-1.77081)	-0.39980 (-1.79313)

TABLE 6-5  
 Developing Property Value Indices  
 For the Project and Control Areas

Year	Property Value Indexes		Residual Index
	Project Area	Control Area	Project Area
1954	100	100	0
1955	59	118	-59
1956	35	102	-67
1957	48	116	-68
1958	64	131	-67
1959	88	232	-144
1960	98	94	4
1961	108	127	-19
1962	119	83	36
1963	132	129	3
1964	189	157	32
1965	192	137	55
1966	176	180	-4
1967	226	199	27
1968	336	177	159
1969	326	266	60
1970	332	249	83
1971	482	240	242
1972	405	284	121
1973	538	275	263
1974	422	252	170

TABLE 6-6

Developed Residential Housing Value Indices  
For the Project and Control Areas

Year	Property Value Indexes		Residual Index
	Project Area	Control Area	Project Area
1963	100	100	0
1964	105	252	-147
1965	111	153	-42
1966	118	120	-2
1967	117	95	22
1968	115	103	12
1969	112	147	-35
1970	109	132	-23
1971	115	143	-28
1972	110	156	-46
1973	133	184	-51
1974	124	189	-65

TABLE 6-7a

Developing Property Subsample  
Impact Value Estimates: Alternative  
Temporal Specifications of the Project's Impact

Year	Impact Values			(4) Durbin Watson Statistic
	(1) Coefficient Value $\hat{N}$ (Student-t)	(2) Percent of Increase in Value	(3) Per Acre Dollar Value of the Increase	
		(%)	(\$)	
1968	163.891 (4.6000)	34.0	3303	1.9003
1969	178.792 (4.8915)	37.1	3604	1.6653
1970	196.765 (5.0579)	40.8	3963	1.2221

TABLE 6-7b

Developed Residential Property Subsample  
Impact Value Estimates: Alternative Temporal  
Specifications of the Project's Impact

Year	Impact Values			(4) Durbin Watson Statistic
	(1) Coefficient Value $\hat{N}$ (Student-t)	(2) Percent of Decrease in Value	(3) Dollar Value of the Decrease	
		(%)	(\$)	
1968	-15.2866 (-0.5787)	13.2	6222	1.7313
1969	-15.4343 (-0.5761)	13.3	6269	1.8172
1970	-21.0050	18.1	8532	1.8402

TABLE 6-8a

Developing Property Subsample Impact Value Estimate: Adjustment Model					
(1) Coefficient Value $\hat{N}$ (Student-t)	(2) Percent Increase in Value %	(3) Per Acre Dollar Value of the Increase \$	(4) Durbin Watson Statistic	(5) Adjustment Coefficient $\theta$ (Student-t)	(6) $R^2$
251.702 (1.489)	52.2	5073	2.0279	.356 (1.232)	.56

---

TABLE 6-8b

Developed Property Subsample Impact Value Estimate: Adjustment Model					
(1) Coefficient Value $\hat{N}$ (Student-t)	(2) Percent Increase in Value %	(3) Per Acre Dollar Value of the Decrease \$	(4) Durbin Watson Statistic	(5) Adjustment Coefficient $\theta$ (Student-t)	(6) $R^2$
-203.432 (-.949)	- *	- *	2.2318	.399 (1.012)	.39

---

\* not calculated because percent decrease would be greater than 100%

lead us to believe that equation (6-40) is a better specification of the model. The latter equation does, in fact, show a positive adjustment process but estimates it as a rather slow phenomenon, adjusting expectations to the difference between previous expectations and reality by only 40 percent (approximately), giving relatively high impact estimates and standard errors of those estimates. We prefer to stay with the specification of equation (6-23).

For the already developed property subsample, we note the negative but insignificant results. This implies that the major impact of extension falls into developable property in terms of increases in property values. Property value on already developed properties changes hardly at all, and if it does change, it is likely to be negative because connection implies that the owner/occupier/resident will have to pay connection fees while he gains little else because his small property is unlikely able to capitalize on potential higher density (unless he demolishes his original dwelling). His service needs may well have been handled by existing on-site equipment which will now be unused.

The Tables 6-7 a and b and 6-8 a and b also report estimates in terms of percentage value changes and dollar value changes. To do this, the estimated coefficient values,  $\hat{N}$ , must be standardized by some reference. Following the general approach used in earlier literature, the coefficients are standardized against the index values of the two types of property: developing and already developed residential property. The percentage values may be expressed as the ratio of  $\hat{N}$  to the values immediately following the project's introduction.

This follows because equation (6-22) or (6-40), in evaluating  $\hat{N}$ , measures the increment to the indices for the two types of properties, and this increment is attributable to the extension of off-site sewerage and water service. Consequently,  $\hat{N}/_{proj} Index_{1971}$  represents the percent change in value that is represented by the project's impact, for example, in the 1970 impact year results.

Using this ratio, a dollar value measure may also be estimated for the increase (or decrease) in property value which can be attributed to off-site service extension. These values correspond to the coefficient values reported in Tables 6-7 a and b and 6-8 a and b, and are given in columns (2) and (3) respectively. The dollar value estimate is based on a \$9,714 dollar (per acre) lot estimate and a \$47,136 house and lot estimate which seemed appropriate from our estimating equations for a 6 acre lot without house more than 800 feet from the Pennsylvania Turnpike and a house defined to be 2 years old with 4 bedrooms, non-masonry, split level on a 22,000 square foot lot more than 800 feet from the Pennsylvania Turnpike.

#### 6.8 Interpretation of the Results

If we collapse our attention to the results of equations (4) in Tables 6-2 and 6-3 and the 1969 estimates of Tables 6-7a and 6-7b, we find that our data looks as:

---

Table 6-9

Comparison of Results (Non Constant Dollars)

Property Type	1956-57 Willingness to pay	TS <sup>c</sup>	1975 Willingness to pay
Developing	4,045*	3,600	2,956*
Developed	4,132	-6,200	4,532

\* per acre for comparability to the TS<sup>c</sup> measure

---

In order to interpret the results we must make them comparable in relevant price bases. Since the data were not previously deflated, the cross-sectional estimates are both reported in current dollars, 1956-57 and 1975, respectively. The TS<sup>c</sup> results, which are based on the BMN indexing and on use of the control of never serviced properties, has already corrected for price changes by using the indexing technique. The TS<sup>c</sup> calculates a per cent price increase (or decrease) on the basis of 1971 data, expresses itself in dollar value using the 1975 price per acre of property and housing prices. Consequently TS<sup>c</sup> is expressed in 1975 dollars. We allow for full comparability by converting then the 1956-57 values into 1975 dollars by using a correction from the consumer price index data on shelter (1975 Statistical Abstract). This alters the comparison:

Table 6-10

## Comparison of Results (1975 dollars)

Property Type	1956-57 Willingness to pay	TS <sup>c</sup>	1975 Willingness to pay
Developing	8,307	3,600	2,956
Developed	8,485	-6,200	4,532

Indeed with the results in Table 6-10 (at least for the developing properties) equality of  $TS^c$  and  $H_{T_0}$  is borne out.

For developing properties, if we assume that there is little price reaction to the project in non-serviced properties then  $TS^c = H_{T_0} = TS'$ , the first equality because of the use of non-serviced control and the second because of the behavioral assumption of lack of non-service property price reaction. In this case from equations (6-37) and (6-38), we have that there is no welfare effect in the J, non-serviced areas for prior owners. We also have that  $k_{T_0}^P - k_{t_0}^P = -5,351$  ( $\equiv 2,956 - 8,307$ ) or  $k_{T_0}^P - k_{t_0}^P = -4,707$  ( $\equiv 3,600 - 8,307$ ), depending upon our choice of  $TS^c$  or  $H_{T_0}$  as our estimate of the left hand side of (6-37) and (6-38). In addition, if we have  $TS' = 2,956$  (or 3,600) and  $H_{t_0} = 8,307$  then from analysis of figure 6-2 we can calculate that the capitalization of benefits of the project into project area land values is equivalent to 2,956 (3,600) and the remaining uncaptured values are equal to the difference 5,351 (4,707). Since the capitalized values

appear from analysis of the differing impact dates (Table 6-7a and 6-7b) to be quickly capitalized, we can assume that these are primarily a payment to the developer. The remaining uncapitalized values are earned as consumer surplus by the owner/occupier of the project area properties. Since we then have existing owners of on-site service suffering a loss in asset position; existing owners of off-site service remaining unaffected; developers profiting to the extent that the land value increment exceeds the developers costs; new owner/residents in the project area benefiting in increased consumers' surplus, it is clear that the project is not partial optimal. While some gain others lose. The losers are bound to be more numerous furthermore, if marginal w/s costs are rising and are above average costs but the w/s firm uses average cost pricing (the latter of which, at least, seems to be an institutional characteristic in w/s markets).

If we assume that there is little price reaction to the project in serviced properties, an entirely different set of conclusions results. In this case  $H_{t_0} = TS'$  and by assumption  $k_{T_0}^P - k_{t_0}^P = 0$ . From equation (6-37),  $J_{T_0}^P - J_{t_0}^P = 5,351 (\equiv 8,307 - 2,956)$  or  $4,707 (\equiv 8,307 - 3,600)$ , implying a welfare gain for non-serviced property owners. From figure 6-2, we believe that in the developing area, the developers gain all that they can, leaving only area GHJ in figure 6-2 for the new owner occupiers.

If we assume that the time series measure, either (1) because of behavioral conditions in the non-serviced and serviced control areas or (2) because the control is far enough removed from the project area that while it picks up the macroeffects of other influences so that it is a good control it does not reflect project influences, is measured by our empirical measure

then we find that the distribution to be yet different. If  $TS' = 3,600$ ,  $H_{t_o} = 8,307$  and  $H_{T_o} = 2,956$ , then  $k^P_{T_o} - k^P_{t_o} = -4,707$ .  $J^P_{T_o} - J^P_{t_o} = 644$ . The benefits of developers are 3,600 and those to new property owner occupants are 4,707.

Other assumptions give other distributions. The only clear conclusion is that each time the distribution changes a different group gains at the relative expense of one of the others. These distributional effects undoubtedly account for enough difference that projects are accepted or rejected by individuals speculation on what the likely outcomes will be in their cases.

To evaluate the impacts on developed property markets, the same type of analysis could be performed as for developing properties. Since the results and conclusions are similar, we hesitate to do so but rather point out the more important departures from the developing property results. The first is the relatively smaller impact of w/s investment on developed property compared with the impact on developing property. The second is the discrepancy between  $H_{T_o}$  and  $TS^C$  in this sample, one estimate positive and the other negative. While we would expect developed property, which is less capable of accomodating the increased density permitted by w/s investment, to be less affected than developing property, the discrepancy between  $H_{T_o}$  and  $TS^C$  is more inexplicable given the results of equations (6-37) and (6-38).

## CHAPTER VII

### SUMMARY

This study has attempted to evaluate rational reasons why water supply regionalization planning so frequently has failed. It is difficult, however, to maintain one's focus on rational reasons and to divorce the subject from irrationality because citizens are emotionally attached to the previously abundant, life-sustaining resource. Actual or imagined growing shortages make individuals feel even more protective of their regional water endowments and this grows into irrational hoarding of the resource. If decision making is irrational, the problem cannot be cured by current research.

One important element in this which must not be ignored by water resources planners is the inherent public distrust of enlarged government or public authorities. Even where an economic study may conclude that a proposed regionalization scheme will yield overall benefits to the region, these benefits will not convince the skeptical resident unless a tangible gain to himself and his neighborhood is forthcoming. After all, any overall benefit to his region may be swallowed up by a seemingly never-saturated bureaucracy of enlarging public institutions. Parkinson's law is rarely represented in economic cost analyses. Thus, plans involving regionalization of existing small systems must be approached by intensified education programs which may incidentally benefit from the information in this report, but to which this report is not primarily intended.

Since regionalization by integration and by extension are basically different, we have studied them separately. We know that the effects of integrating regionalization are, for the most part, reflected only in the

market for water supply. There is little spillover into other markets and the resultant distributional effects work out in variation of water supply pricing applied to the various areas. Since insufficient historical record on pricing (following integration) has been established, our attention on integration focuses primarily on efficiency and the distribution. Extension regionalization, on the other hand, involves both water and property markets because water availability is a locational characteristic that becomes capitalized in property values as it is extended into previously unserved areas. This makes analysis of distributional effects more complex, and for that reason we concentrate on questions of distribution in regionalization integration. This leads to two major thrusts of this work.

First, the efficiency of plans for regional integration are evaluated. This is done initially without reference to existing plant and equipment, giving long run, unconstrained, optimal solutions. Integration plans are also evaluated assuming a given level of fixed plant and equipment. The difference between the cases shows considerable impedance of regionalization from long-lived plant and equipment. While economies of scale are generally present in water supply programs, their effects are more evident when supply comes from a single source than when the supply is split among sources. Given existing fixed plant and equipment at two or more potential regional sources, regionalization will optimally (in general) use some of the capital equipment at each of the sites. This may often imply a small gain relative to pipe connection and pumping costs.

We have found that there is little scale economy when water supplies are developed from ground water sources. Marginal water costs are nearly constant because small and finite supplies available from any given pump and well installation require multiple wells for enlarging capacity and

consequently regionalization of several communities gains little at the expense of greater interconnection and pumping costs. Conversely, surface supply systems depart considerably from this finding, producing substantial economies by increasing capacity at a single point rather than at several. It is in this context that the existence of previous capital investment is important in constraining the extent to which capacity will be drawn from single or multiple sources.

Consideration of water supply shortage costs heighten the usefulness (efficiency) of regionalization. The models we develop assume equalization of marginal shortage costs among regional partners although this is unlikely to occur in practice without improving pricing policy. Better pricing would increase the value of regionalization, but the lack of it as in the past does not fully discount regionalization benefits. The engineering formulae developed to measure water shortage costs are subject to error whenever proper marginal cost pricing is not practiced. These formulae implicitly overestimate shortage costs whenever marginal costs are not equalized among communities and users.

Lack of hydrologic variation in the humid Eastern regions limits the usefulness of routine water sharing that could occur by regionalizing supplies among basins. The general level of overcapacity of current reservoirs in the humid East (at least as indicated by our New York high flow skimming case study) makes high flow skimming a valuable technique, and a useful form for regionalization in two or more basins. In general, however, capacity adjustments necessary to implement high flow skimming reduce the efficiency of skimming as a regionalization technique.

Our second major thrust demonstrates that any given water supply

(/sewerage) project can produce distributional consequences which may cause rejection of regional plans. The distributional effects impact in the land market where consumers historically have appeared so eager to protect asset values that we might expect some irrationality. Any distributional effects in the land market may be blown out of proportion by emotionalism. Distributional impacts may be felt in housing in neighborhoods adjoining the extended service area and certainly the impacts will affect directly properties receiving the water supply project. The latter effect distributes benefits between developer and ultimate property owner/resident. The distributional effects in neighboring properties are primarily asset revaluation.

Measurement of the land value impacts is difficult, but the complexity of choice of empirical methods suggests why there has been such divergence of empirical results (measuring various environmental impacts) in the past. It is precisely the divergence of empirical measures that gives us the opportunity to gain some information on the distribution. In the final analysis, however, we fail to derive a theoretically suitable measure for the actual impact over time because of the equivalence of the time series component as it is employed (and has been employed in previous work) and one of the cross-sectional measures. As a consequence the distributional impacts are indeterminate, forcing us to analyze impacts by assuming the state of certain land market conditions. The sensitivity of impacts to the various market conditions sufficiently changes the distributional implications that we believe distribution may well be a major cause for regionalization failure.

Much more work remains to be done in land value study in order to

identify the measures which are so difficult to obtain. We hope that our work will foster continuing interest in this and other areas. If the distributional implications of regionalization projects can be determined, then compensatory policies can negate their effect in regionalization rejection. Such policies will aid the success of regionalization planning. They will also constructively provide revenue for suburban parks that are all too often in conflict with high density water investments.

APPENDIX A

Coding System for Property Value Data  
From Montgomery County Sewerage Systems  
and Land Value Study,  
January 1976

<u>Card I</u>		<u>Card II</u>	
<u>Column</u>	<u>Data</u>	<u>Column</u>	<u>Data</u>
1-2	Municipality Code	1-2	Municipality Code
3	Blank		
4-7	Block Number	3-4	Block Indicator
8	Blank	5-8	Block Number
9-11	Unit Number	9-11	Unit Indicator
12	Blank	12-14	Unit Number
13	Dwelling Type	15-16	Second Sale Data
14	Property Use	17-21	Lot Size in Sq. Ft.
15	Converted	22-25	Lot Size in Tenths of Acres
16	Stories		
17	Levels	26-32	Second Selling Price
18	Exterior	33-34	Third Sale Date
19	Basement	35-39	Lot Size in Sq. Ft.
20	Heating	40-44	Lot Size in Tenths of Acres
21	Central Air		
22-26	Number of Rooms	45-50	Selling Price Third
27	Number of Bedrooms	51-52	Fourth Sale Date
28	Fireplace	53-57	Lot Size in Sq. Ft.
29	Number of Baths	58-61	Lot Size in Tenths of Acres
30	Garage		
31	Number of Cars	62-67	Fourth Selling Price
32	Swimming Pool	68	Area Code
33	Streets	69-70	Estimated Date of Latest Land Sale
34	Water		
35	Sewerage		
36	Blank		
37-40	Construction Date		
41	Blank		
42-43	First Sale Year		
44	Blank		
45-52	Selling Price (x10 <sup>1</sup> )	<u>Note:</u>	Card No. I also applies for single sale observations.
53-54	Blank		
55-59	Lot Size in Sq. Ft.		
60	Blank		
61-65	Lot Size in acres in hundredths (000.00)		
66	Blank		
67-68	Year Accessed by a Street		

CARD III

<u>Column</u>	<u>Data</u>	<u>Column</u>	<u>Data</u>
15-16	Fifth Sale Date	40-44	Lot Size in Tenths of Acres
17-21	Lot Size in Sq. Ft.		
22-25	Lot Size in Tenths of Acres	45-50	Sixth Selling Price
		51-52	Seventh Sale Date
26-32	Fifth Selling Price	53-57	Lot Size in Sq. Ft.
33-34	Sixth Sale Date	58-61	Lot Size in Tenths of Acres
35-39	Lot Size in Sq. Ft.	62-67	Seventh Selling Price

DWELLING TYPE		EXTERIOR	
No.	Code	No.	Code
1	Detached	1	Frame
2	Vac. Res. Land	2	Masonry
3	Row	3	Other
4	Semi-Detached		
5	Res - Comm.		BASEMENT
6	Condominiums	No.	Code
7	Mobile homes	1	Full
8	Other	2	Partial
		3	None
PROPERTY USE		HEATING	
No.	Code	No.	Code
1	Single	1	Hot air gravity
2	Duplex	2	Hot air forced
3	Triplex	3	Electric
4	Quadruplex	4	Steam
5	Res - Comm.	5	Hot water
6	Other	6	Other
		7	None
CONVERTED		CENTRALIZED AIR CONDITIONING	
No.	Code	No.	Code
1	Yes	1	Yes
2	No	2	No
3	Unknown could not gain entrance to building		
STORIES - NON SPLIT		BEDROOMS	
No.	Code	Code	Number of Rooms
1	1 Story	1	1
2	1 1/2	2	2
3	2	3	3
4	2 1/2	4	4
5	3 or more	5	5
6	None	6	6 or more

**FIREPLACE**

No.	Code
1	Yes
2	No

**STREETS**

No.	Code
1	Paved
2	Unpaved

**BATHS**

No.	Code
1	1
2	1 1/2
3	2
4	2 1/2
5	3
6	3 1/2
7	4 or more
8	None

**WATER**

No.	Code
1	Municipal Water
2	Other

**SEWERAGE**

No.	Code
1	Sewer
2	Septic Tanks

**GARAGE**

No.	Code
1	Attached
2	Detached
3	Car port
4	Basement
5	None

**NUMBER OF CAR GARAGE**

No.	Code
1	1
2	2
3	3 or more
4	None

**SWIMMING POOL**

No.	Code
1	Above ground
2	Below ground heated
3	Below ground unheated
4	None

MUNICIPALITY CODE

11	Lansdale
34	Franconia
35	Hatfield
39	Low Gwynedd
46	Montgomery
53	Towamencia
56	Upper Gwynedd

AREA CODE

1	Always Serviced Control Area
2	Never Serviced Control
3	Project Area

CODE FOR TAPES

LWLC 9	Source Data from <u>WORLCO</u>
LWLC 10	Towamencin
LWLC 11	Franconia
LWLC 12	Upper Gwynedd

**APPENDIX B**

**Comparative Data on Control  
and Project Areas**

TABLE 1

Comparative Housing Characteristics  
(1960)

Housing Characteristics	Study Area Townships			County Township		
	Towamencin (1)	Franconia (2)	Lansdale (3)	Average	Range	
					Low	High
Condition	%	%	%	%	%	%
Sound	98.29	91.86	93.77	93.25	58.24	98.69
Deteriorating	1.52	7.48	5.59	5.47	1.23	36.48
Dilapidated	0.19	0.66	0.64	1.28	0.0	9.54
Housing Tenure	%	%	%	%	%	%
Owner	77.73	78.15	70.45	75.14	55.14	89.23
Renter	16.30	18.16	27.06	20.86	7.72	41.84
Vacant	5.97	3.69	2.49	4.00	1.40	21.78
Person/Unit	3.74	3.75	3.17	3.40	2.96	3.88

- (1) Project area  
(2) Never-serviced control  
(3) Always-serviced control

TABLE 2

Comparative Housing Characteristics  
(1960)

Housing Unit Type	Study Area Townships						County Township	
	Towamencin (1)		Franconia (2)		Lansdale (3)		Average	Range
	No.	%	No.	%	No.	%	No.	Low High No. No.
1 Family	976	(92.5)	871	(82.4)	3327	(82.2)	2117 (85.8)	102 14942
2 Family	22	( 2.1)	154	(14.6)	382	( 9.5)	109 ( 4.4)	0 1049
Multi-Family	57	( 5.4)	32	( 3.0)	337	( 8.3)	242 ( 9.8)	0 3668
TOTAL	1055		1057		4046			

Value of Owner Occupied Housing	No.		No.		No.		No.	
	No.	%	No.	%	No.	%	No.	%
Less than \$ 5,000	-	( 0.0)	4	( 0.7)	24	( 0.9)	31	( 1.8)
\$ 5,000 to \$ 9,999	33	( 4.7)	60	(10.2)	595	(21.9)	253	(14.7)
\$10,000 to \$14,999	177	(25.3)	196	(33.2)	1317	(48.5)	581	(33.7)
\$15,000 to \$19,999	386	(55.1)	227	(38.4)	509	(18.7)	386	(22.4)
\$20,000 to \$24,999	76	(10.9)	68	(11.5)	161	( 5.9)	180	(10.4)
\$25,000 or more	28	( 4.0)	36	( 6.1)	109	( 4.0)	294	(17.0)

Median Value	\$16,300	\$15,900	\$12,500	\$15,000
--------------	----------	----------	----------	----------

- (1) Project area
- (2) Never-serviced control
- (3) Always-serviced control

TABLE 3

## Comparative Population Characteristics

Population Characteristics	Study Area Townships			County Township Average
	Towanemcin (1)	Franconia (2)	Lansdale (3)	
POPULATION/SQUARE MILE				
(1950)	165	196	3309	731
(1960)	383	276	4275	1070
(1970)	487	370	6171	1292
MEDIAN AGE				
(1970)	27.5	27.5	29.2	30.8
PERCENT NON-WHITE				
(1960)	0.0	0.0	0.4	3.8
(1970)	0.2	0.1	0.8	4.0
PERSONS PER HOUSEHOLD				
(1960)	3.73	3.75	3.17	
(1970)	3.55	3.66	3.03	

- (1) Project area  
(2) Never-serviced control  
(3) Always-serviced control

TABLE 4

COMPARATIVE INCOME CHARACTERISTICS

Family-Income Characteristics	Study Area Townships			County Township		
	Towamencin (1)	Franconia (2)	Lansdale (3)	Average	Range	
	(%)	(%)	(%)	(%)	Low (%)	High (%)
<b>DISTRIBUTION</b>						
\$ 0 - \$ 3,999	11.08	16.14	15.89	12.60	6.23	28.48
\$ 4,000 - \$ 6,999	31.47	40.60	35.17	30.90	19.81	51.29
\$ 7,000 - \$ 9,999	33.23	34.97	30.92	25.80	14.39	38.60
\$10,000 - \$24,999	22.26	16.34	17.07	25.81	7.36	42.69
\$25,000 and over	1.24	1.95	.95	4.89	0.0	19.82
<b>MEDIAN INCOME</b>	\$7409	\$6424	\$7004	\$7632	\$5902	\$12204

- (1) Project area
- (2) Never-serviced control
- (3) Always-serviced control

## BIBLIOGRAPHY

- Abt Associates Inc. Factors Affecting Pollution Referenda. Final Report to Environmental Protection Agency, Washington: U.S. Government Printing Office, 1971.
- Advisory Commission on Intergovernmental Relations. Intergovernmental Responsibilities for Water Supply and Sewage Disposal in Metropolitan Areas. Washington: U.S. Government Printing Office, 1965.
- Anderson, R. J. and T. D. Crocker. "Air Pollution and Property Values." Urban Studies, October, 1971, pp. 171-180.
- Aron, G., T. M. Rachford, J. Borrelli, W. Stottmann, "A Method for Integrating Surface and Ground Water Use in Humid Regions," Institute For Research on Land and Water Resources, No. 76, The Pennsylvania State University, February 1974.
- Avrin, M. E. "Some Economic Effects of Residential Zoning in San Francisco," unpublished paper, Stanford University, 1975.
- Bahl, Roy W., Stephen P. Coelen, and Jeremy J. Warford. "Use of Land Value Increments as Estimates of the Benefits of Water Supply and Sewerage Investments in Developing Countries," unpublished manuscript, 1975.
- \_\_\_\_\_, Stephen P. Coelen and Jeremy J. Warford. "Land Value Increments as a Measure of the Net Benefits of Urban Water Supply Projects in Developing Countries: Theory and Measurement." Government Spending and Land Values: Public Money and Private Gain. C. Lowell Harriss, Ed. Madison Wisconsin: The University of Wisconsin Press, 1973, pp. 171-188.
- Bailey, M. J., R. F. Muth, and H. O. Nourse. "A Regression Method for Real Estate Price Index Construction," Journal of the American Statistical Association, December, 1963, pp. 933-942.
- Beattie, Bruce R., et al. "Economic Consequences of Interbasin Water Transfer." Agricultural Experiment Station, Technical Bulletin 116, Oregon State University, Corvallis, June, 1971.
- Black and Veatch, "Standardized Procedure for Estimating Costs of Conventional Supplies," Report to the Office of Saline Water, 1963.
- Borrelli, John, "Formulation of Economic Procedures for Sizing Municipal Water Supply Systems," Ph.D. Thesis, Civil Engineering, The Pennsylvania State University, University Park, Pennsylvania, June 1973.

- Boyce, David E. et al. "Impact of Rapid Transit on Suburban Residential Property Values and Land Development - Analysis of the Philadelphia Lindenwald High Speed Line," Phase One Report to Office of the Secretary, U.S. Department of Transportation. Philadelphia: Regional Science Department, Wharton School, University of Pennsylvania, November, 1972.
- Boyd, Keith A., and Frank A. Bell, Jr., "A Rationale for the Regionalization of Public Water Systems," Water Resources Bulletin, Vol. 9, No. 1, February 1973, pp. 73-80.
- Centre Regional Planning Commission, "Centre Region Comprehensive Plan, 1974," Centre Region, Pennsylvania, June 1974.
- Chiogioji, M., and E. Chiogioji. Evaluation of the Use of Pricing as a Tool for Conserving Water. Water Resources Report No. 2, Washington: Washington Technical Institute, November, 1973.
- Coelen, S. P. Model Development in Water Resources Research: Theory and Measurement, unpublished dissertation, Department of Economics, Syracuse University, 1973.
- \_\_\_\_\_, "Synthetic Review of Recent Air Pollution Research," a paper, Northeast Regional Science Review, Vol. 3, April, 1973.
- Coelen, S. P. and W. J. Carroll. "Measuring Change in the Housing Market," Conference on Research in Income and Wealth: Economics of Residential Location and Urban Housing Markets. New York: National Bureau of Economic Research (forthcoming).
- Davis, O. and K. Wertz. "The Consistency of Assessment of Property: Some Empirical Results and Managerial Suggestions." Applied Economics, Vol. 2, 1969, pp. 151-157.
- Denny, Charles S. "Wisconsin Drifts in the Elmira Region, New York and Their Possible Equivalence in New England," American Journal of Science, Vol. 254, No. 2, February 1956, pp. 82-95.
- Dobson, A. Price Changes of Single Family Dwelling Units in Racially Changing Neighborhoods, unpublished dissertation, Department of Economics, Washington University, 1970.
- Downing, Roger and Dean Jansma. "Economic Impact of Public Investment on Property Value in York County, 1950-1965," State College, Pennsylvania: Institute for Research on Land and Water Resources, 1970, Appendix A.
- Edel, Matthew. "Land Values and the Costs of Urban Congestion: Measurement and Distribution," paper presented at "Man and His Environment," a Symposium on Political Economy of Environment, Paris, France, July 1971.

- "ENR Indexes Expected to Rise Sharply in 1974," Engineering News Record, Vol. 1912, No. 12, March 21, 1974, pp. 62-63.
- Freeman, A. M., III. "Air Pollution and Property Values: A Methodological Comment," Review of Economics and Statistics, December, 1971, pp. 415-416.
- \_\_\_\_\_, "Spatial Equilibrium, The Theory of Rents, and The Measurement of Benefits from Public Programs: A Comment," Quarterly Journal of Economics (forthcoming).
- Fritz, Richard G. "Regional Planning for Water Resource Management: An Investment Scheme for a Rapidly Growing Community," unpublished manuscript, 1976.
- Gotzmer, W. G. "Engineering and Economic Considerations for the Regionalization of Water Supply Systems in Small Communities," Master of Science Thesis and Interim Report to the U.S. Army Corps of Engineers, Institute for Water Resources, March 1976.
- Grieson, Ronald R. "The Economics of Property Taxes and Land Values." A paper presented at the Econometric Society Winter Meetings, December, 1971.
- Griliches, Zvi. "Hedonic Price Indexes for Automobiles: An Econometric Analysis of Quality Change," The Price Statistics of the Federal Government, General Series, No. 73. New York: National Bureau of Economic Research, 1961.
- Grima, A. P. Residential Water Demand: Alternative Choices for Management. Toronto: University of Toronto Press, 1971.
- Groves, R. H., "Joint Discussion--Northeastern U.S. Water Supply Study: Coming Water Supply Crisis," Journal of American Water Works Association, Vol. 63, No. 5, May 1971, pp. 311-312.
- Hanke, S. H. and J. J. Boland. "Water Requirements or Water Demands," Journal of American Water Works Association, Vol. 63, No. 11, 1971, pp. 677-681.
- Hartman, L. M. and Don Seastone. Water Transfers: Economic Efficiency and Alternative Institutions, Resources for the Future, John Hopkins Press, Baltimore, 1970.
- Hogarty, Thomas F. and Robert J. Mackay. "Price Elasticity of Demand for Residential Water," Department of Economics, Virginia Polytechnic Institute and State University (in press).
- Hufschmidt, M. M. and M. B. Fiering. Simulation Techniques for Design of Water-Resource Systems, Harvard University Press, Cambridge, Massachusetts, 1966.

- Kish, L. and J. B. Lansing. "Response Errors in Estimating the Values of Homes," Journal of the American Statistical Association, Vol. 49, 1954.
- Krouse, Michael R. "Quality of Life and Income Redistribution: Objectives for Water Resources Planning," The Center for Economic Studies, Institute for Water Resources, Army Corps of Engineers, July 1972.
- Lancaster, K. L. "A New Approach to Consumer Theory," Journal of Political Economy, April, 1966, pp. 132-156.
- Langley, C. J. "Adverse Impacts of the Washington Beltway on Residential Property Values," Land Economics, February, 1976, pp. 54-65.
- Lave, L. B. "Air Pollution Damage: Some Difficulties in Estimating the Value of Abatement," in A. V. Kneese and B. T. Bower (eds.), Environmental Quality Analysis, Baltimore: John Hopkins Press, 1972.
- Lewis, W. Cris et al. Regional Growth and Water Resource Investment. Lexington, Massachusetts: D. C. Heath, 1973.
- Mera, K. "Tradeoff Between Aggregate Efficiency and Interregional Equity: A Static Analysis," Quarterly Journal of Economics, Vol. 81, 1967.
- Mera, K. "Tradeoff Between Aggregate Efficiency and Interregional Equity: The Case of Japan," Regional and Urban Economics, Vol. 3, No. 3, August 1973.
- Muellbauer, J. "Household Production Theory, Quality, and the Hedonic Technique," American Economic Review, Vol. 64, December 1974, pp. 977-994.
- Musgrave, R. A. The Theory of Public Finance, New York, 1959.
- New Jersey Department of Community Affairs and Division of State and Regional Planning, "Secondary Impact of Regional Sewage Systems," June, 1975.
- Nourse, H. O. The Effects of Public Housing on Property Values in St. Louis, unpublished dissertation, Department of Economics, University of Chicago, 1962.
- Polinsky, A. Mitchell and Steven Shavell. "Amenities and Property Values in a Model of an Urban Area," Journal of Public Economics, 1976.
- Quinn, Frank, "Water Transfers," Geographical Review, 58(1): 108-132, 1968.
- Quirk, Lawler and Matusky Engineers, "Hydraulic Analysis of the New York City Water Supply System," North Atlantic Division, U.S. Army Corps of Engineers, September 1974.

- Radosevich, "Electoral Analysis of the Clean Water Bond Law of 1974: Patterns of Support in a Continuing Environmental Issue," Institute of Governmental Studies, Working Paper No. 15, University of California, Berkeley.
- Ridker, R. G. and J. A. Henning. "The Determinants of Residential Property Values with Special Reference to Air Pollution," Review of Economics and Statistics, May 1967, pp. 246-257.
- Robbins, Richard T. 1975 Parametric Estimates of Costs for Tunnelling in Rock, Tunnelling Technology Newsletter, National Research Council, No. 12, 1975.
- Roberts, W. J., "Water Hauling by Trucks in Illinois," Ill. Water Survey Circ. 106: 12 pp., 1971.
- Rosen, S. "Hedonic Prices and Implicit Markets: Production Differentiation in Pure Competition," Journal of Political Economy, January, 1974.
- Russel, Clifford S., David G. Arey, and Robert W. Kates. Drought and Water Supply, John Hopkins Press, Baltimore, 1970.
- Sauerlender, Owen H., et al., "Criteria for Regionalization of Water and Waste Management Systems," Institute for Research on Land and Water Resources, No. 84, The Pennsylvania State University, 1974.
- Spencer, Milton H. Contemporary Economics, Worth Publishers, Inc., New York, 1974, pp. 375-391.
- Strotz, R. H. "Use of Land Rent Changes to Measure the Welfare Benefits of Land Improvement," Unpublished paper submitted to Resources of the Future, Washington, D.C., July 1966.
- U.S. Army Corps of Engineers, Northeast U.S. Water Supply Study. Analysis of Regional Water Supply Programs for the Northern New Jersey-New York City-Western Connecticut Metropolitan Area. Washington: U.S. Government Printing Office, 1973.
- U.S. Army Corps of Engineers, Northeast U.S. Water Supply Study. Evaluation of Alternative NEWS Water Supply Systems for the Northern New Jersey-New York City-Western Connecticut Metropolitan Area. Washington: U.S. Government Printing Office, 1974.
- U.S. Army Corps of Engineers, Northeast U.S. Water Supply Study. Organizational, Legal, and Public Finance Aspects of Regional Water Supply. Washington: U.S. Government Printing Office, July 1972.
- U.S. Department of Health, Education and Welfare. Problems in Financing Sewage Treatment Facilities. Washington: U.S. Government Printing Office, 1973.

- Urban Systems Research, Inc. Interceptor Sewers and Urban Sprawl: The Impact of Construction Grants on Residential Land Use, Vol. I and II, Prepared for the Council of Environmental Quality, Springfield, Va.: National Technical Information Service, 1974.
- Warford, J. J. The South Atcham Scheme: An Economic Appraisal. Her Majesty's Stationery Office, London, 1969.
- Yao, Kuan M. "Regionalization and Water Quality Management," Journal Water Pollution Control Federation, Vol. 45, No. 3, March 1973, pp. 407-411.
- Young, G. K., R. S. Taylor, and J. J. Hanks. "A Methodology for Assessing Economic Risk of Water Supply Shortages," Final Report: U.S. Army Corps of Engineers, Institute for Water Resources, IWR Report 72-6, Alexandria, Virginia, May 1972.

Aron, Gert

Economic and technical considerations of regional water supply / by Gert Aron and Stephen P. Coelen. -- Ft. Belvoir, Va. : U.S. Institute for Water Resources, 1977.

198 p. (IWR contract report ; 77-7)

Prepared by Institute for Research on Land & Water Resources, Pennsylvania State University under Contract DACW31-75-C-0018.

1. Water supply. 2. Reservoirs. 3. Regional planning. I. Title. II. Coelen, Stephen P., joint author. III. Series: U.S. Institute for Water Resources. IWR contract report no. 77-7

HD1694

.A42

U584

no.77-7

