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The land development process is assumed to operate in two stages - first come a small number of priming actions which establish the broad framework for the more numerous secondary actions which follow. Sewage transmission systems are important priming actions whose economic characteristics are poorly understood. The primary purpose of this thesis is to investigate the economic characteristics of sewage transmission systems in order to make the land use planning process better informed, more rational, and more responsive to social objectives.

First the thesis addresses the questions, should sewage transmission systems be publicly provided, and if so, how much of the service should be provided? It is shown that sewage transmission services exhibit significant externalities in consumption and production, and that as a criterion for selecting the most preferred level

of output the maximization of net monetary benefits is insufficient. It is suggested instead that an array of the significant monetary and non-monetary effects of alternative systems be presented, and that the most preferred outcome be selected by a political procedure.

Secondly, the production and cost characteristics of sewage transmission are investigated, the costs of distance are explored, and an attempt is made to estimate the value of sewage transmission services. This information is applied in an empirical investigation of two hypothetical sewage transmission systems for the Tualatin River Basin in Washington County, Oregon. The Tualatin Basin contains the rapidly urbanising western edge of the Portland metropolitan area. Proposal I assumes no spatial limitation on suburban expansion, and additional population is distributed throughout the entire study area in continuous low-density settlements. Proposal II assumes that additional population is restricted to the existing urban areas and population density increases, but the rapid extension of the suburban fringe is halted. The empirical study shows that it is possible to increase the net direct monetary benefits from the production of sewage transmission services, and, at the same time, halt the extension of the urban fringe.

An Economic Study of Sewage Transmission and Land Use: An Empirical Application

by

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AN ECONOMIC STUDY OF SEWAGE TRANSMISSION AND LAND USE; AN EMPIRICAL APPLICATION

INTRODUCTION

The origins of this research are founded in an attempt to understand the concept and value of open-space in and around urban areas. For this purpose open-space may be defined as all land and water surfaces not covered by buildings or permanent structures. There is a growing awareness by individuals and by society that open-space is a scarce resource that needs to be allocated rationally. To undervalue open space, or to treat it as a free good necessarily results in its overuse, exploitation and disappearance. Rapid technological change, a rapidly growing population and an absence of coordinated collective decision making are three powerful forces which exert strong pressures on all natural resources, including open-space land. It is the recognition of this conflict and the awareness of potentially irreversible impacts that form the foundation of the economics of resource conservation (Wantrup, 1952).

Unfortunately, to put open-space into a resource conservation framework for analysis, necessitates the definition, classification and measurement of open-space. But open-spaces do not sort themselves well according to form, function or value. Very little open-space does not perform a variety of functions, whose value may vary from one individual to another and over time. For example farmland or open green-space frequently serves as a buffer-strip adjacent to highways, and at the same time provides aesthetic relief for the traveller, as well as a habitat for plant and animal life.

"Openness" may be considered as just one characteristic of all landforms that are not built upon. Yet a market for "openness" generally fails to exist, while other land characteristics, such as location, soil fertility and freedom from flood hazard, are actively traded. For "openness" is an environmental good, owned in common, which must be managed by some collective choice mechanism, if it is to be conserved efficiently.

Open-space is considered by some as an "amenity resource", a resource contributing to the quality of life, but the concept of amenity still remains vague. It would require imaginative studies in environmental perception, the evaluation of intangibles, and social psychology to gauge directly actual values that alternative quantities and distributions of open-space create. Such studies we can do little more than speculate about at this time.

It is because of such problems of perception, definition, measurement and evaluation, that attention was turned away from open-space itself, towards a study of one of the principle forces that can create or remove open-space from the landscape. The subject chosen for study was the urban sewer system and its effects on population dispersal and land use. Sewage transmission systems are one of a number of priming actions which, individually and collectively, precondition and establish the framework within which individual residential location decisions are made.

Some Philosophical Considerations

Before proceeding further it is necessary to make a small digression to identify two philosophical themes which pervade this thesis. The first concerns the role of the scientist in research in the social sciences. The second concerns the nature of scientific information as an input to decision-making. I hope that an appreciation of these two positions will clarify the reasons for the approach taken in the research reported here.

Karl Popper proposes a theory of the growth of knowledge which suggests that reliable knowledge grows by subjecting our proposed solutions to problems to severe critical tests (Popper, 1968). Propositions which survive repeated testing may be considered as the science of the times. Thus as a rationalist, and as a believer in the applicability of the scientific method to social questions, Popper maintains that the best we can do as social scientists is to bring rational criticism to bear on the problems that face us, and on our proposed solutions. That is, we should be asking questions such as: "Is this proposed action likely to produce the expected or desired result?" But it is not the task of social science to predict the course of future events, and Popper demonstrates elsewhere that, for strictly logical reasons, this is impossible (Popper, 1964). Rather, the main task of theoretical social science is to help man choose wisely among competing actions, by tracing the unintended consequences of intentional human actions. Only when both the immediate and the more remote consequences of alternative actions are understood, prior to a decision, can an rational choice be made. This is one theme which runs through my approach to this thesis.

A second theme is that we are no longer living in a world where events "just happen". Instead, increasingly events must be "made to happen", if society is to move towards the achievement of the goals that it considers to be desirable. Social processes can no longer be viewed as the outcome of impersonal forces which we can observe, but which are beyond our control. Julian Huxley has observed that man's power over biological and cultural evolution is so great that he has no choice but to determine his own destiny. This he achieves through the rational planning and manipulation of the systems within his reach (Huxley, 1964). Huxley calls this directed cultural evolution, but in a more practical vein this is the essence of all planning processes.

Metropolitanism, Urbanisation and Suburbanisation

Given the impossibility of evaluating the concept of open-space directly, and given an acceptance of the main task of theoretical social science as being the identification of the unintended consequences of intentional human actions, it is necessary to approach the problem indirectly. The approach taken in this thesis is to examine in detail just one of the principle forces that has the power to extend the built-up area, and transform open-space to closed-space. The reasons for this oblique approach can be found by examining the phenomenon called metropolitanism.

Metropolitanism refers to the concentration of a population in a small number of metropolitan areas. It is one phenomenon that characterises the changing distribution of the growing population of the United States. From 1790 to 1900 the U. S. population not only grew from 4 to 76 million, but the number of cities with more than 100,000 people went from zero to 37. During the twentieth century the U. S. population has been predicted to expand to over 314 million, with over 70% of this number located in 223 major urban areas (Pickard, 1969). This movement follows a transition from a mainly agrarian, extensive-land-using economy to an industrial, technological, capital-intensive economy.

Throughout this thesis the word <u>urban</u> will be informally defined as meaning a locational setting, where population density is higher than elsewhere, whose population is engaged in non-primary occupations, and which serves as a cultural, economic, and administrative center of a region peripheral to the urban area. Urbanisation is the rate of change in the proportion of a population living in urban settlements. Empirical studies show that as the proportion of a population that is urban increases, urbanisation proceeds first at an increasing rate and then at a decreasing rate. In Western societies, as the proportion of the population that is urban approaches 75%, urbanisation approaches zero (Davis, 1965). Beyond this point urban growth may continue, but the proportion of the population living in urban areas appears to remain stable, as shown in Figure 1.1.

In the U.S., as urbanisation slows down suburbanisation appears to increase. Suburbanisation refers to the rate of movement of population from urban centres to the urban periphery. Suburbanisation is not in itself a new phenomenon, it has been proceeding for some time, but in the past the extent of suburbanisation was small, and many of its effects have been concealed. For example in an overbounded city, where the legal city is larger than the geographic or physical city, any redistribution of population from the central city to the fringe may very well occur within the legal and statistical boundaries. Thus, in the aggregate, the transfer goes unnoticed. A second factor which may conceal the extent of past suburbanisation is that many cities have expanded their legal boundaries over time, and the census statistics, which apply at a point in time, make intra-urban population movements difficult to identify.

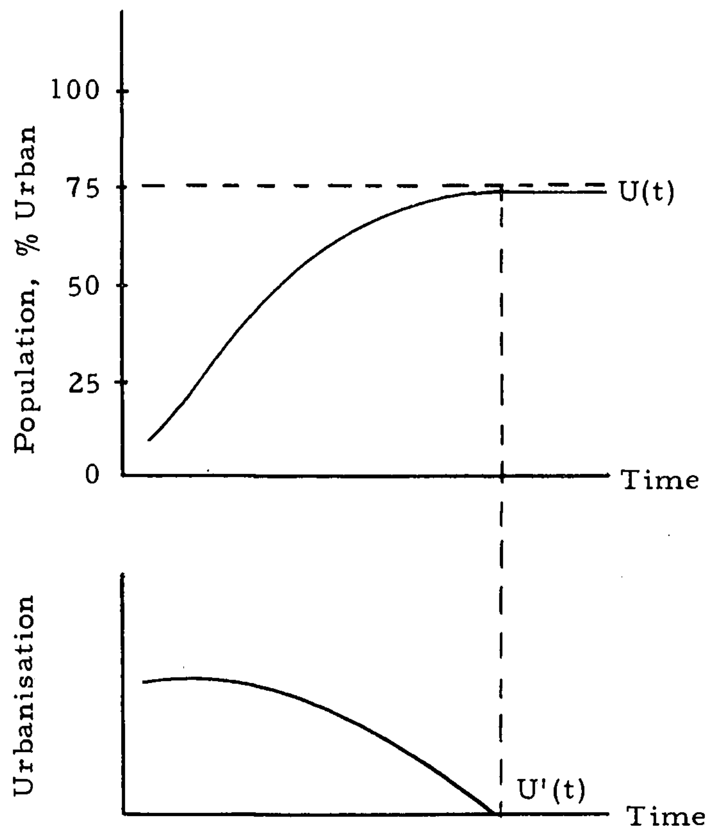


Figure 1.1. A graphic representation of the process of urbanisation.

During the post-war years numerous factors have combined to accelerate suburbanisation. There has been a rapid increase in the number of households. For example, more than 10 million new households were created in the decade 1948-1958. There have also been shifts in job locations from the central city to the suburbs, together with changes in transportation and communication systems. A detailed account of recent trends can be found in Clawson, (1971) and the changing residential function has been examined by Birch (1970). Both authors conclude that it is practically impossible to determine cause and effect when examining shifts in economic activity and population. But the implications of the shifts are clear. Overall population densities are falling, and rural land on the urban periphery is being drawn into urban use at an increasing rate. Analysis of the four major Metropolitan Regions in the U. S. (the Atlantic, Great Lakes, Californian and Floridian Metropolitan Regions) shows a marked decline in population densities that is considered likely to proceed further (see Table 1. 1).

Table 1. 1 Past and projected future population densities of Metropolitan Regions in the U. S.

Year	Population density, persons per square mile, in Metropolitan Regions in the U. S.	
1920	6010	
1930	5922	
1940	5820	
1950	5713	
1960	4762	
1970	4436	
1980	4278	Projected
2000	4217	

(Source: Pickard, 1969, p. 26-31, 35-41).

Examination of the population statistics for Portland, Oregon (the city adjacent to the study area used in this thesis) reveals similar trends in metropolitanism, urbanisation and suburbanisation. Portland, like other Standard Metropolitan Statistical Areas (S. M. S. A. 's) in the western U. S., differs from the national average by never having reached the very high central city populations that characterise older established eastern cities, and also by having suburbanisation proceed at a much higher rate than is typical. During the decade 1960-1970 this four county S. M. S. A. contained three of the four fastest growing counties in the State of Oregon. Multnomah, Clackamas and Washington Counties experienced percentage increases in population of 33.3, 46.9 and 71.2 percent respectively, during this ten year period. At the same time the State of Oregon grew in population by 18.2 percent, and 12 of the 36 counties in the State experienced population declines. It is worthwhile observing that Washington and Clackamas Counties, which contain the bulk of the Portland suburban area, were the two fastest growing counties in the State. (All population figures cited are drawn from the U. S. Department of Commerce, 1970, Bureau of the Census, as reported by the Center for Population Research, Portland State University.)

Land Use Planning

Population pressure from suburban residential settlement is therefore one of the major forces exerting strong pressures on natural resources within and around growing urban areas. A land use plan is one of the principal tools employed to control and direct these forces. A plan is a method devised for achieving some goal(s) or objective(s). Land use planning is concerned with controlling the location, intensity of use, and quantity of land needed for space using activities in accordance with a community's goals. City planning has been defined as

> ...a means of systematically anticipating and achieving adjustment in the physical environment of a city, consistent with social and economic trends. It involves a continuous process of deriving, organising, and presenting a broad and comprehensive program for urban development and renewal. It is designed to fulfill local objectives of social, economic, and physical well-being, considering both immediate needs and those of the forseeable future (Chapin, 1965, p. iv).

Thus the definition comes to resemble Wantrup's definition of the optimum state of conservation of a resource. Conservation is the redistribution of rates of resource use towards the future. The optimum state of conservation is the time distribution of use rates that maximises the present value of the flow of expected net revenues from a resource (Wantrup, 1952, p. 51, 77).

However, in reality, the land use pattern of an area at a point in time represents the accumulated effects of many past decisions made by a host of participants. The planned or unplanned public acts of providing highways, schools, and water and sewer systems appear to possess real power in shaping land use patterns. According to Chapin and Weiss,

> We may conceive of land development as a consequence of certain priming actions which precondition and establish the broad framework for the mass of secondary actions that follow and make up the bulk of the pattern observed. Taken together the priming and secondary actions are said to produce the land use pattern. Such a rationale places a premium on discovering and studying how and why priming actions occur (Chapin and Weiss, 1962, p. 431).

A land use plan is therefore a control system. It controls the process of land development. But land development is a system itself. A system is a set of interconnected parts. Each part may be seen as a system in itself, and the whole system may be regarded as but one part of a larger system. That is, there are interdependent hierarchies of systems.

The consequences of public actions are often most clearly visible when it is recognized that the activity, on which the public action operates, is part of a wider system. Systems analysis is a research strategy designed to aid a decision maker facing complex problems of choice under uncertainty. It has been defined as

> . . . a systematic approach to helping a decision maker choose a course of action by investigating his full problem, searching out objectives and alternatives, and comparing them in the light of their consequences using an

appropriate framework (Quade and Boucher, 1968, p. 2).

Cybernetics is the study of control systems. One of the principle characteristics of many effective control systems is isomorphism. That is, a control system must have similar form to the system that it seeks to control. For example, assume that the activities in a behavioral decision system can be represented as follows:

Goal formulation
↓ ↑
Inventory of resources
↓ ↑
Proposed alternative courses of action
↓ ↑
Evaluation of alternatives
↓ ↑
Action

Figure 1.2. Diagramatic outline of a simple behavioural system.

The principle of isomorphism would suggest that to effectively control this behavioural system would require a decision-making procedure of similar form. A failure to formulate a goal or goals at the outset would jeopardise effective control. Omitting the inventory of resources that constrain action would also inhibit effective control. An effective decision making system would parallel the postulated behavioural system from goal formulation to action. Thus, if the behavioural systems within a community that seek to promote community goals possess a form similar to that postulated in the diagram above, then the control system (the community plan) should possess a similar form.

A community may contain a hierarchy of systems seeking to achieve community goals. A land use plan is simply one control system at a low level in this hierarchy, contributing to more ultimate ends. A transportation system is an example of an even lower level system, contained within the land use plan, that seeks to promote the goals of the land use plan, and hence the more ultimate goals of the community.

Consider a hierarchy of three systems, as in Figure 1.3. Level one represents activities that promote the most ultimate goals of society. Examples of such goals may be such deeply held <u>values</u> as survival, security, belonging and order. Level two represents <u>goals</u> drawn as directly as possible from the values expressed in level one, still idealised, but expressed as real world processes and conditions. Examples of these are, a decent home environment, full employment, and adequate public services. On level three are found specific operational <u>objectives</u>, subject to objective definition and measurement, and conforming to goals on level two. Operational objectives are often called standards (fixed minimum levels of performance) or targets (fixed levels of desired performance). By the use of standards or targets decision making processes can be routine.

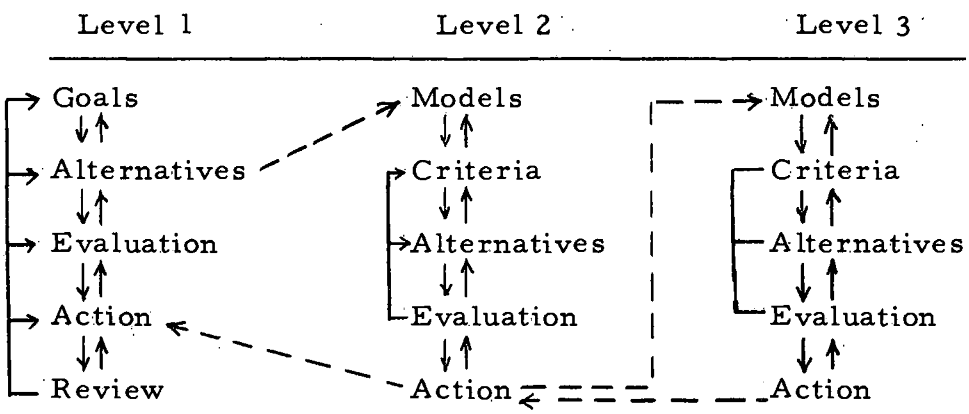


Figure 1.3. Diagramatic outline of a hierarchy of decision levels.

A land use plan is therefore just one control system in a hierarchy of control systems. If it is consistent, the goals of the land use plan (level two) seek to achieve the ultimate values of society (level one) by promoting subordinate, but operational objectives (level three). It is the objective of this thesis to report an investigation of an operational urban system on the third level in the proposed hierarchy.

Sewage Transmission Systems

Even cursory examination of the process of land development in an urban environment quickly reveals a complex set of interdependencies. "Everything depends on everything else." But it is naive to move from this valuable insight to the false assertion that no specialised or particular analysis can be valid or meaningful. This thesis focuses attention on just one important urban system, the sewage transmission system. It is the hope that this study will be of value in itself, and of value as a complement to the studies of other urban systems that have been undertaken.

Sewage transmission systems were chosen for three principle reasons. First, the subject has been neglected to date. Transportation, electric power, water, gas, and fire protection systems have been studied in detail elsewhere. (An overview and bibliography of this work can be found in Clawson, 1971). Second a sewage transmission system is a good example of a priming action, as defined by Chapin and Weiss, which pre-conditions and establishes the broad framework of land development. It is a tactic contributing to a land use strategy. A strategy is a comprehensive approach to resource use to meet ultimate goals. A tactic is a limited action designed to meet more proximate goals. Tactics are subordinate to strategy, and strategic ends are limited by tactical capabilities (Bella and Overton, 1971). A principle objective of this thesis is to examine the economic implications of the tactical capabilities of sewage transmission systems. Third, during recent years many communities have been faced by problems of rapid population increase and suburban expansion, accompanied by unacceptable levels of environmental pollution. Private solutions to the problems of sewage transmission and disposal are failing, and the need for coordinated collective action is arising. This problem is unlikely to diminish during the near future, for the people-pressure on the already overtaxed capacity of the natural environment to absorb wastes harmlessly seems likely to increase.

Details of recent local government expenditures on sewer and sewage disposal can be found in the Census of Governments produced by the U. S. Bureau of the Census. Local governments include county, municipality, township, school district and special district governments. All sewer and sewage disposal expenditures are locally authorized expenditures, even though they may include some State or Federal funds. The Census of Governments does not list sewage collection, transmission and treatment expenditures separately, but for typical urban situations, collection and transmission represent 82% of total expenditure, with 18% for treatment.[1/]

For metropolitan areas (S. M. A. or S. M. S. A.) for the years 1957, 1962 and 1967, expenditures for sewer and sewage disposal fell from $8.31 per capita in 1957 to $7.18 per capita in 1967. Expressed alternatively, expenditure per acre of urban land fell from $3,060.46 per acre in 1957 to $2,516.53 per acre in 1967. If, as population grew from 1957 to 1967, some economies of scale for sewer service were generated, then per capita expenditures could fall and the quality of service remain undiminished. But from 1957

[1/] Source: U. S. Department of Commerce, Census of Governments.

to 1967 population was redistributed from central cities to suburbs, the opportunity to capture scale economics was reduced, and population densities fell, from 368 to 351 per square mile. Given these conditions it would have required greater expenditures per capita to provide an equal level of sewage transmission and collection services.

Table 1.2 Local government expenditures on urban sewage collection and transmission services, 1957-1967, in constant dollars.

U. S. Urban Areas	1957	1962	1967
Population	85,430,988	112,885,178	132,160,000
Land area, square miles	231,991	310,233	376,829
Sewer collection and transmission expenditures ($ million)	710.0	845.3	948.3
-- per capita. $	8.31	7.49	7.18
-- per acre $	3,060.46	2,724.73	2,516.53

Source: U. S. Department of Commerce, Census of Governments, 1957, 1962, 1967.

Waste disposal usually consists of the removal of wastes from their site of production, and/or rendering them harmless or unobjectionable (Downing, 1969). Domestic wastes take the form of rubbish, garbage and sewage. Rubbish is mainly inorganic, combustible or noncombustible, solid wastes. Garbage is domestic food wastes. Sewage is the organic waste and spent water produced in the community. Engineers now euphemistically refer to sewage as waste water. It is a combination of liquid and solid wastes suspended in water, together with any ground-water, surface water and storm water that may be present. The wastes are the byproducts of human activity and arise from residential, commercial, industrial and institutional activity. Normally sanitary and storm sewage are collected and transported separately, but some older communities still operate combined sewers.

Sewerage in the process of conducting sewage from its point of origin to the point of treatment or release. Sewerage is divided into collection, the removal of sewage from its point of origin into small sewers (lateral and branch sewers), and transmission, the transport of sewage from small sewers, via large sewers (mains and interceptors) to the point of treatment or release.

This thesis investigates the economics of sewage transmission within urban residential areas, for it is these transmission systems which directly affect population distribution. Sewage collection is a less significant private decision, made by individual householders, when a connection to a main sewer is made. Sewage collection, unlike transmission, is not a collectively provided good. When private septic tanks are inadequate or unsuitable, sewage treatment is generally a collective good. Treatment costs are however mainly a function of plant capacity and level of treatment performed. The per capita costs of treatment decrease as the population served increases, and the per capita cost of treatment increases as the level of treatment increases. Assuming uniform standards of water quality between urban areas within a river basin, treatment costs should not affect the suburban land conversion process. Instead it is the main sewage transmission system that will most directly affect land use changes.

The Study Area

Following a theoretical investigation of sewage transmission systems and an analysis of public expenditures, an empirical investigation of a sewage transmission system proposed for the Tualatin River Basin, in Washington County, Oregon, was undertaken. An understanding of the relevant characteristics of the study area can best be obtained by examining the land and water, population, and institutional features that prevail, and the history of the sewer system crisis that emerged. Much of this description of the study area comes from the Tualatin Basin Water and Sewerage Master Plan (Stevens, Thompson and Runyan, 1969).

Land and Water Characteristics

The Tualatin River Basin is located almost entirely within the boundaries of Washington County, Oregon. The basin covers approximately 730 square miles or 486,400 acres. Of this, over 200,000 acres are used in agricultural production. Most of the study area is covered by clayey unconsolidated soil, termed Willamette Silt. As a medium for the subsurface disposal of waste water, this soil can be classified as marginal or poor, that is, unless detailed examination proves otherwise, the soil is unacceptable for this purpose. In addition, throughout the study area, ground water occurs very close to the surface, and surface ponding occurs during the wettest months of the year. Topographically the area is generally flat. Streams tributary to the Tualatin flow generally from the north and west, and the Tualatin River flows eastward, discharging into the Willamette River at the eastern limits of the study area. The lower reaches of the Tualatin are liable to flooding during the winter and spring when precipitation and surface run-off are at their peaks. Thus the stream flows in the Tualatin are highly irregular, with high streamflow December-April, and low flow for the rest of the year. About 70% of the annual flow occurs during December-March.

Water quality in the Tualatin and its tributaries fluctuates daily and seasonally, and generally declines from the headwaters to the mouth of the river. During the summer months when streamflow declines and temperature of the water increases the water quality declines sharply.

Thus geologically the study area is poorly drained, with a water table close to the surface. It is unsuitable for subsurface disposal of sewage, and is liable to seasonal flooding. The Soil Conservation

Service of the U. S. Department of Agriculture has classified the whole of Washington County as unsuitable for septic tanks because of the severe soil limitations (U. S. Department of Agriculture, Soil Conservation Service, 1971). Hydrologically, the seasonally fluctuating streamflows of the Tualatin River and its tributaries make sewage discharge into the rivers during the low flow months extremely hazardous to water quality.

Population Characteristics

In 1970 the population of Washington County was 157,920, and this has been projected to increase to over 350,000 during the next thirty years (see Table 1.3). Fifty-five percent of the population reside in eight urban and four rural communities. The remaining 45% is located in numerous small unincorporated areas which are presently experiencing very rapid urban development. The population distribution and the recent urbanisation of eastern and central Washington County follow the major highways that provide access to the Portland metropolitan area. The Pacific, Tualatin Valley and Sunset Highways are the major automobile transportation routes, and residential communities have spread, almost uninterruptedly, along them. As residential development spreads westward, consolidated urban growth gives way to small, scattered residential and commercial developments, mingling with agricultural enterprises.

Recent demands for land use changes have been for mainly urban uses, and for housing in particular. Population pressure during the last 30 years has been severe, and during the 1960's this has resulted in the transfer of approximately 2000 acres of farmland annually to urban use.

Table 1.3. The population characteristics of Washington County, Oregon, 1900-2000.

Year	Population	Average annual increase, %
1900	14,467	
1910	21,552	4.90
1920	26,376	2.24
1930	30,275	1.48
1940	39,194	2.95
1950	61,269	5.63
1960	92,237	5.05
1970	157,920	7.12
2000	350,000	4.05 (Projected)

Institutional Characteristics

Until very recently planning for water, sewage and related public services has been in the hands of a large number of small, independent organizations. Prior to the formation of the Unified Sewerage Agency of Washington County in 1970, water and sewer services were administered by nearly 60 different cities and special districts. Examination of the 5-yearly U. S. Department of Commerce Census of Governments for the years 1957, and 1967 show that as the urban population in the study area grew from 82,947 to 128,000, per capita expenditures on sewer services barely increased from $8.44 to $8.83, in constant dollars. During this period population densities in metropolitan areas in Oregon fell dramatically, from 246 to 128 persons per acre, and it would have been necessary for expenditures to increase as population density fell if service of equal quality was to be maintained during the decade. Thus we may conclude that during a period of rapid population expansion sewer services provided by the numerous small districts in the study area suffered a decline in quality. Other evidence of the inability of the small districts to provide adequate services comes from the facts that during this period several existing sewage treatment plants reached their capacity output, excess sewage entered streams and rivers untreated, and water quality fell continuously.

The Problem in the Study Area

The sewer problems of the Tualatin Basin are the result of extreme population pressure on a geographic area with land and water characteristics that are inadequate to naturally absorb the wastes generated by the population increase. The many small institutions that have arisen to cope with the problem have proved to be inadequate. Problems resulting from rapid population expansion have been in evidence for some time. A comprehensive master plan for sewage was first developed, but not implemented, in 1956. To quote from the Master Plan;

> Solution to the sewerage problem in the study area has usually been the construction of sewers and sewage treatment plants with effluent disposal into streams which are practically dry in summer (Stevens, Thompson and Runyan, 1969, p. 3).

It was not until the water pollution problem reached crisis proportions that comprehensive action to provide adequate sewer service was undertaken.

> The seriousness of the existing situation relative to the sewerage in the study area was emphasised on September 13, 1966, when the Oregon State Sanitary Authority adopted the following policy regarding waste treatment in the Tualatin Basin:
>
> 1. That until a master plan of sewerage is developed and adopted no new sewerage and waste facilities and no expansion of existing facilities other than those previously committed be approved for construction in the Tualatin Basin unless provisions are included to prevent discharge of the effluent to the Tualatin River or its tributaries during the low flow season - normally June 1 to November 1, and
>
> 2. Those in charge of existing facilities ... start immediately to comply ... with Sanitary Authority policy ... to achieve proper disinfection before effluents are released to the receiving stream.
>
> This policy was formally reaffirmed by the Sanitary Authority two years later on September 27, 1968 (Stevens, Thompson and Runyan, 1969, p. 3).

However, these directives from the Sanitary Authority were insufficient to evince action from the community at large, for on September 26, 1969 the State Environmental Quality Commission ordered that;

> Until appropriate plans and methods of financing were found to resolve the waste water disposal problems of Washington County and an agency with authority to implement the plan had been established, future connections to the sewers of the County would be banned (Potter, 1971, p. 1859).

Thus the Master Plan and the agency charged with its implementation were only taken seriously when all further sewer connections were prohibited and a building ban was imposed. Individuals and communities in the Tualatin Basin had been imposing non-reciprocal external diseconomies on downstream water users. It required the State Environmental Quality Commission, a multi-river-basin "firm", to force recognition of their polluting activities on these individuals and communities. This sequence of events however, should come as no surprise, for as Mancur Olson has pointed out in his study of collective action, if members of a large group rationally seek to maximize their personal welfare, they will not act to advance their group objectives unless there is coercion to force them to do so, or unless some separate incentive exists (Olson, 1965, p. 2).

The Procedure

The procedure followed in this research, and the outline of this thesis are as follows. Because it was quickly recognized that the economic characteristics of open space, a common property amenity resource, could not be measured and evaluated directly, attention focused instead on the characteristics of a poorly understood urban system, sewage transmission, a system with power to shape the land use pattern. The procedure followed involved inputs from two disciplines, economics and civil engineering. In Chapter I the problem has been defined.

In Chapter II two political-economic questions are addressed. Firstly, should sewage transmission be a publicly provided good, and if so, how much of the good should be provided? These questions are answered in terms of the theory of welfare economics, including the modern formulation of externality theory, and by reference to both benefit-cost analysis and the emerging new political economy.

In Chapter III the physical production function for sewage transmission is investigated. System capacity is examined with respect to population density, drainage basin area and distance of sewer connections from the site of sewage treatment.

Given the physical production function, the cost function for sewage transmission systems are defined. This is followed by an investigation of the extent of the benefits that accrue to land, in the process of residential development, by the provision of sewage transmission services. Costs and benefits are observed to vary with system size, population density and distance from the source of the service.

In Chapter IV the information generated in Chapter III is applied to an empirical investigation of a number of alternative sewage transmission systems for the Tualatin River Basin, Washington County, Oregon. The alternatives were chosen in order to identify the nature and extent of costs, benefits and other effects of different degrees of suburban containment.

In Chapter V the major conclusions of the four preceeding chapters are summarized. Conclusions of particular interest to economists and non-economists are identified and, where possible, they are integrated. Conclusions are related both to the general problem of sewage transmission in an urbanising area, and to the Tualatin River Basin study area.

WELFARE ECONOMIC THEORY AND THE PROVISION OF PUBLIC GOODS

The main purpose of this chapter is to address and answer two fundamental questions. Firstly, should sewage transmission systems be publicly provided goods, and if so, how much of the good should be provided. Steiner separates issues of public policy into these two classes of questions. Questions of the first type belong to the theory of public interest, and this is concerned with the origins and articulation of the demand for public action. Questions of the second type belong to the theory of marginal public expenditure, and this is concerned with the allocation of scarce public resources among competing public demands (Steiner, 1969). In fact the two types of questions are not entirely separate. They are interdependent, but the separation is a convenience that enables us to observe the whole process of public goods provision more clearly.

The Theory of the Public Interest

All human actions are either individual or collective actions, and are either private or public actions. We may reasonably assume that rational and self-interested individuals undertake some action in order to achieve a preferred state at the minimum cost. The need for collective action arises when a group of individuals perceives that it cannot achieve its individual objectives unaided. That is, groups exist to further the interests of the members of groups. Governments are simply one type of group, but they are distinct in one important way from other groups in that the goods which they provide are publicly induced. A collective good is not necessarily a collective consumption good. To quote Steiner;

> Collective goods arise whenever some segment of the public collectively wants and is prepared to pay for a bundle of goods and services other than what the unhampered market will produce.
>
> Collective goods may be publicly or privately provided ... When the coordinating mechanism for providing a collective good invoke the powers of the state, it is hereby defined as a public good (Steiner, 1969, p. 7).

Public goods therefore require some distinct act of legitimization, a private collective concern is transformed by a legal act to a public collective concern.

In the United States the abandonment of the market in favour of the public provision of certain goods has been made on pragmatic rather than doctrinaire grounds (Castle, 1965). The economist is fortunate to possess analytic concepts with which he may assess the performance of both market and non-market phenomena. Economic criteria for favouring public action can be found in the modern formulation of externality, as outlined by Bator (1958) and Buchanan and Stubblebine (1962).

Bator identifies three forms of externality, <u>ownership</u>, technical, and public goods externality, and residential sanitary sewage transmission systems exhibit, to some degree, externalities of all three forms.

Ownership Externality

Consider two individuals, A and B, both of whom discharge sewage into a common pool. Individual A is aware of the dangers associated with the build up of untreated sewage and is also sensitive to the unpleasant aesthetic side-effects, therefore, he treats his sewage to remove or deactivate any harmful materials. Individual B is also aware of these dangers, but in addition he recognizes the interdependence of his own and A's actions. Assume that the utility functions of both individuals are functions of treatment, T, and all other goods, M, and also that the utility of B is also dependent on the treatment performed by A.

$$U_A = U_A (M_A, T_A)$$

$$U_B = U_B (M_B, T_B, T_A)$$

Let the price of treatment be P_t and the price of all other goods P_m. If we maximize the sum of the utilities of the individuals subject to a total income constraint, C, we obtain

$$C = M, P_m + T, P_t$$

Let $$V = U_A (M_A, T_A) + U_B (M_B, T_B, T_A) + \lambda (C - M, P_m - T, P_t)$$

then $$\frac{\partial V}{\partial M_A} = \frac{\partial U_A}{\partial M_A} - \lambda P_m = 0$$

$$\frac{\partial V}{\partial M_B} = \frac{\partial U_B}{\partial M_B} - \lambda P_m = 0$$

$$\frac{\partial V}{\partial T_A} = \frac{\partial U_A}{\partial T_A} + \frac{\partial U_B}{\partial T_B} - \lambda P_t = 0$$

$$\frac{\partial V}{\partial T_B} = \frac{\partial U_B}{\partial T_A} - \lambda P_t = 0$$

Setting these partial derivatives equal to zero yields

$$\frac{\dfrac{\partial U_A}{\partial M_A}}{\dfrac{\partial U_A}{\partial T_A} + \dfrac{\partial U_B}{\partial T_A}} = \frac{\dfrac{\partial U_B}{\partial M_B}}{\dfrac{\partial U_B}{\partial T_B}} = \frac{P_m}{P_t}$$

If $\frac{\partial U_B}{\partial T_A} = 0$ then no ownership externality exists and the first order conditions for maximizing utility subject to an income constraint are identical to those produced under the usual assumptions of consumer behaviour.

If $\frac{\partial U_B}{\partial T_A} > 0$ an external economy is conferred by A on B, and the quantity of other goods, M, used to produce treatment will be less than the socially desirable quantity.

If $\frac{\partial U_B}{\partial T_A} < 0$ an external diseconomy is conferred by A on B, and the quantity of other goods, M, used to produce treatment will be greater than the socially desirable quantity.

Technical Externality

Technical externalities arise from two sources, indivisibility or increasing returns to scale.

To explain indivisibility consider the production function $Q = A (K, L)$, where output, Q, is a function of inputs K and L. Assume that input K is only available in certain discrete quantities K_1, K_2 and K_3, unlike input L which is assumed to be infinitely divisible. Assume further that a producer is initially operating at the point D in the Figure 2. 1., maximizing output subject to total cost, C. Let P_K and P_L be the price of inputs K and L respectively.

If total costs should increase from C to C', other things remaining unchanged, shifting the isocost line away from the origin to a new tangency at D', then the producer is free to operate at d_1, d_2, or d_3, but not at the efficient point D'.

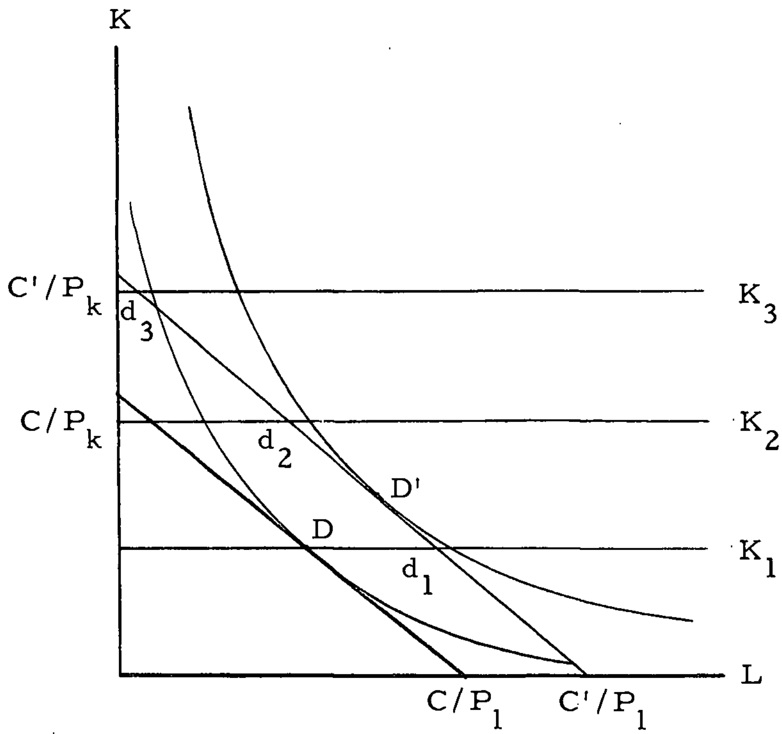


Figure 2. 1. Isoquant map with factor K indivisible.

At D' ,
$$\frac{\frac{\partial Q}{\partial K}}{\frac{\partial Q}{\partial L}} = \frac{P_K}{P_L}$$

At d_1 ,
$$\frac{\frac{\partial Q}{\partial K}}{\frac{\partial Q}{\partial L}} < \frac{P_K}{P_L}$$

At d_2, d_3
$$\frac{\frac{\partial Q}{\partial K}}{\frac{\partial Q}{\partial L}} > \frac{P_K}{P_L}$$

The production of sanitary sewage transmission and treatment are subject to indivisibilities. The land area served and the scale of plant available exist only in certain discrete sizes. For example in a rapidly urbanising area, a proposal to expand the sewer system may be confined to a limited choice between expanding the system to drainage basin X, Y or Z. The drainage basins are of finite size, and in order to satisfy criteria of engineering feasibility, one whole basin or sub-basin may be chosen, drainage basins are not infinitely divisible.

A welfare maximum cannot be sustained when production processes are subject to increasing returns to scale. Under these conditions the associated average cost at any level of output is falling, and this implies that the associated marginal cost, while it may be rising, will lie below the average cost (see Figure 2.2).

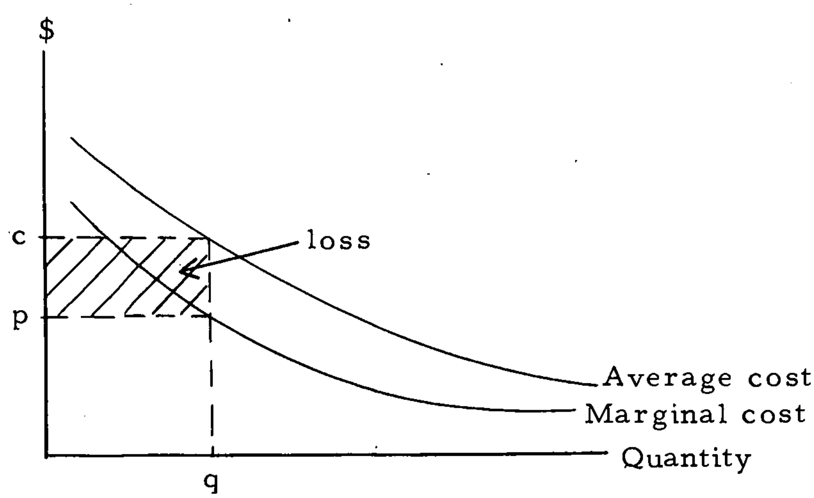


Figure 2.2. Production at a "loss" with marginal cost pricing and average cost continuously declining.

If maximum welfare requires price equal to marginal cost, smoothly increasing returns to scale results in production at a loss, and there is an incentive to create a monopoly or to produce zero output. A natural monopoly is said to exist when a single producer can serve an entire market at the lowest per unit cost, and self-policing competition cannot survive.

Public Goods Externality

Samuelson has defined the singular characteristic of a pure public good as being --- each individual's consumption of such a good leads to no subtractions from any other individual's consumption of that good (Samuelson, 1954). In fact there are probably very few examples of pure public goods. The case of the lighthouse is one frequently discussed in the literature. In some societies a lighthouse will benefit everyone, but it is unlikely that lighthouse services will be produced privately. For the operator cannot ration his output, and "free-riders" could use the light without reimbursing the operator. The lighthouse beams are indivisible and no one can be excluded from the benefit yielded by the service. Considerable external economies in consumption exist. In many respects a sewage transmission system does not closely approximate this ideal. But certain benefits from sanitary sewage, such as improvements in public health and water quality in receiving streams, are such that individuals all benefit equally, and access to these benefits cannot be denied. When these benefits are appreciated, the incentive to become a "free-rider" is created. An individual who fails to join a collective sewer system may do so in the hope of gaining the benefits from an improved environment, and at the same time believing that his small output of untreated effluent will make an insignificant negative impact. Additionally there has been in the past an unwillingness to impose connection charges on new users when they gain access to an existing system. And, in the case where a system is operating at less than full capacity the incremental load imposed by a marginal user is negligible.

It should be emphasised that Samuelson's definition of a public good externality is quite different from Steiner's definition of a public good. The former is analytical, the latter is behavioural. The three forms of externality identified by Bator are forms of market failure. These may be regarded as necessary conditions, or as a prima facie case, for public intervention into otherwise private markets. For if Steiner's view of public goods is accepted, then the final articulation of the public interest is a political process. But it is necessary to identify, as Bator has done, the basis of collective concern. For sanitary sewer systems, the basis for collective action can be found in all three forms of externality. Sewer services possess characteristics of ownership, technical, and public goods externality. As populations increase in size and income, as the corresponding ability to generate wastes increases, and the natural capacity of the environment to absorb and harmlessly degrade wastes is overtaken, the basis for collective concern increases. Thus we may conclude that with respect to the theory of the public interest, sewage transmission services may qualify as collective goods warranting public action.

The Theory of Marginal Public Expenditures

The theory of marginal public expenditures is usually found in the literature of benefit-cost analysis. Benefit-cost analysis has been defined as "the collection and organization of data relevant by some conceptually meaningful criteria to determining the relative preferredness of alternatives" (Krutilla, 1961). Benefit-cost analysis is therefore normative, it addresses questions of what ought to be done and how any given goal can be attained (Friedman, 1953). As a tool benefit-cost analysis is built upon welfare economic theory; if public action is legitimate (by virtue of market failure) it should be based upon criteria which seek to improve the general welfare of society. Some critics of welfare economic theory argue that it is unnecessary since in a democratic society problems of economic policy not solved by the market mechanism can be left to the democratic process. But this separation into either "market" or "political" decision areas is naive. As outlined above markets may fail, but democratic processes may also "fail." Mishan identifies three forms of "political failure" (Mishan, 1969). Firstly, democratic decision-making is expensive of time and effort, and for numerous insignificant decisions it is an irrational process. Secondly, in a party political state there is no reason to assume that majority decisions always respect widely held views. Even in a non-party state it is a myth to attribute to the voice of the people, unlimited wisdom (Popper, 1968, p. 347). Thirdly, if democracy is more than just "majority-rule", but is a means of reaching collective agreement through reasoned argument, then there is a need for consistency, and the development of uniform decision-making criteria. Thus wholly political allocation processes may fail on grounds of efficiency, ethics, or consistency. Once it is recognized that markets can fail and political processes can also fail, then the value of welfare economics in guiding public policy appears to increase.

The basic economic criterion for selecting the optimum level of investment in a project is the maximization of the present value of the estimated net benefits associated with project. Stated alternatively in marginal terms, increases in project investment should continue until the incremental benefit is just equal to the costs associated with that increment. If total investment is less than optimal then the costs of increasing investment are less than the possible benefits. If total investment is greater than optimal then the costs saved by decreasing investment exceed the benefits foregone by the decrease. A major advantage of the net benefits criterion is its broad applicability to all kinds of decision problems, and not merely to public investment decisions. The rationality of the decision rule makes it appropriate for the evaluation of multi-purpose water resource developments (where it has been frequently used) to analysis of institutional rule changes, such as city-county government consolidation.

Diagramatically, the determination of the optimum quantity of output from a project can be represented as in the Figure 2. 3.

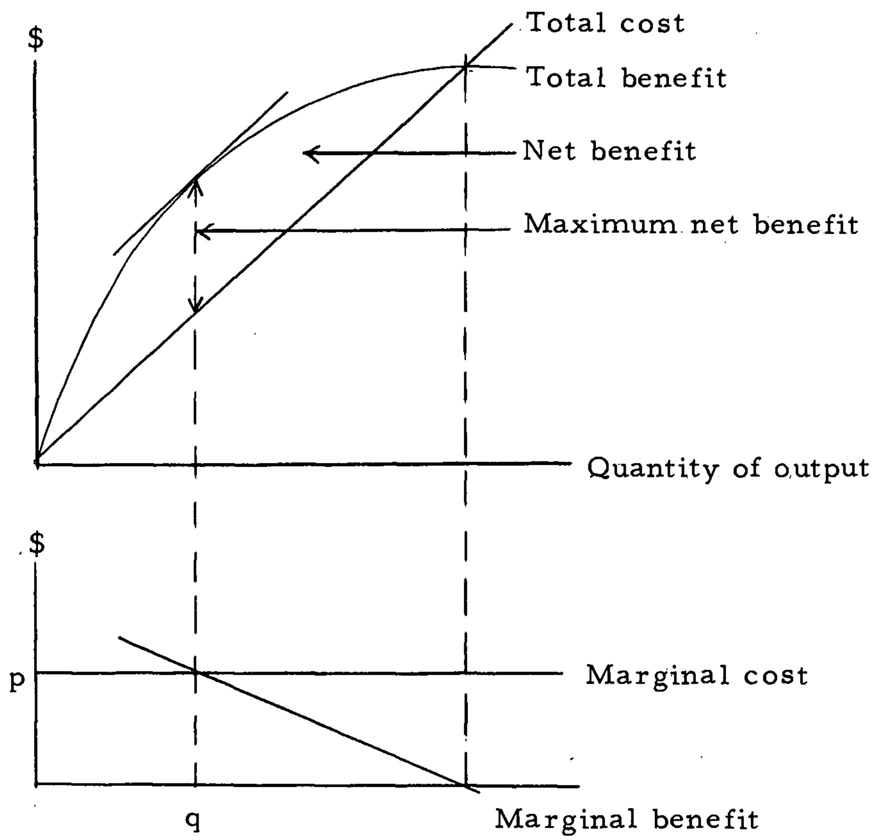


Figure 2. 3. Diagramatic respresentation of optimum project output.

Mathematically the net benefits criterion becomes

maximize PVNB $= \sum_{i=1}^{n} \frac{B_i - C_i}{(1 + r)^n}$

where PVNB = present value of net benefits.

B_i = project benefits in time period i.

C_i = project costs in time period i.

r = discount rate of future benefits and costs.

n = project life.

or dPVB(S) = dPVC(S)

where dPVB(S) = marginal present value of benefits from the project as a function of size, S.

dPVB(S) = the marginal present value of benefits from the project as a function of size, S.

If a choice is to be made from an array of alternatives of the optimum sewage transmission system, the net benefits criterion can be represented as follows.

Maximize Z $= \sum_{i=1}^{n} V_i N_i - \sum_{i=1}^{n} C_i$

subject to V_i, N_i and $C_i > O$

where Z = net benefits from sewage transmission

V_i = value of one unit of transmission in system of size i.

N_i = number of units of transmission in a system of size i, $N_i = N_i(C_i)$.

C_i = cost of investment in system of size i.

Taking the derivative of Z with respect to C_i, where $N_i = N_i(C_i)$, and setting this equal to zero, yields

$$dZ = V_i dN_i = dC_i$$

and

$$\sum_{i=1}^{n} V_i dN_i = \sum_{i=1}^{n} dC_i = dC$$

That is, the change in total project cost, dC, is equal to the sum of the changes in project benefits.

Also

$$V_i = \frac{dC_i}{dN_i} = MC_i \text{ for all i.}$$

That is, investment in sewage transmission should continue until the benefit, V_i, from an additional unit of transmission is equal to the marginal cost of that unit. This is the efficient solution.

Efficiency is however, only one objective of almost all public resource development projects. Other objectives may be the attainment of a more desirable income distribution, the enhancement of the physical environment, and other impacts on human well-being (U. S. Water Resources Council, 1971). Thus the possibility of trade-offs between efficiency and non-efficiency objectives exists.

If <u>all</u> project effects (positive and negative) could be identified, measured, and found to be commensurable, would there be just one socially efficient solution to the question of optimum project size? That is, with perfect specification of the net benefits criterion, would there be no divergence between private and social benefits and costs? The answer is probably, yes. But the hypothetical question denies the existence of the real problems of evaluation that beset project analysis, and will probably remain unresolved. For as long as the divergence between private and social costs exists, problems of natural resources development will remain normative and prescriptive.

Leaving aside problems of equity, the environment, and human well-being, can the net benefits argument be applied to the selection of the optimum sewage transmission system? What problems face the analyst in attempting to set the sewage transmission problem into a benefit-cost framework? In particular, how can V_i and C_i, the value and cost of an increment of a public good be measured?

The Supply and Demand of Public Goods

Price formation in a market economy is one function of the interaction of the forces of demand and supply. Based upon indifference curve analysis and assuming that each consumer attempts to maximize satisfaction from a given money income, the analyst can derive individual demand curves for commodities. The demand curve shows the maximum quantity of the good that will be purchased at a given price per unit time. The aggregate demand curve is the horizontal sum of the individual demand curves.

On the supply side, the production function defines the relationship between the quantities of factor inputs and product output. For a given production function and given factor prices, a cost function can be defined which relates production cost to level of output, and from which can be determined the least cost means of producing a given level of output. The short-run supply schedule of a competitive firm is its marginal cost curve for all outputs above the point of minimum average variable cost. The aggregate supply curve is the horizontal sum of the individual supply curves. Unfortunately for public goods the demand and supply schedules possess different derivation and different interpretation.

Neoclassical economics provides a theory for the demand and supply of private goods. Economic theory is built in three stages, going from a set of behavioural hypotheses, such as if price falls then quantity demanded increases, via an institutional structure, the competitive organization of firms and consumers in a market, finally to a set of inferential predictions, such as, prices for similar factors will be equalized (Buchanan, 1968). The inferential predictions become testable conjectures only if the institutional structure is accepted, and therefore the derivation of the institutional structure becomes a legitimate task for economic theory. For public goods the legitimization of demand is made through political institutions and these are not analogous to the competitive market form.

<u>The Supply of Public Goods</u>

Governments of all levels supply tangible goods and services, such as health care and mass transit systems, and intangible services, such as marketing orders and zoning regulations, to communities, using scarce resources to satisfy community wants. The array of public outputs is therefore diverse and the quantitative measurement of output is difficult. Sewage transmission services have well defined and measurable physical characteristics, gallons of capacity per unit area per unit of time (usually millions of gallons per acre per day). This output can be considered as qualitatively homogeneous, a million gallons of capacity in one location is identical to a million gallons of capacity in all other locations. Other characteristics of these locations may vary, but the quality of a unit of sewage transmission capacity is constant. It is also characteristic of public agencies in democratic societies to strive for uniformity of service between individuals or locations, except where income redistribution is an explicit objective. Qualitative differences may occur in the provision of public services but it is often difficult to measure directly the values of qualitatively different outputs. Various proxy measures may be used. For example, if more sewage treatment improves public health by reducing the occurence of an infectious disease, then the reduced probability of infection may be a suitable proxy for the quality of sewage treatment. Sewage transmission systems either function, or they do not function, and there is no real qualitative distinction between alternatives. A group merely imposes a greater or lesser quantitative demand on the system according to the population density of the group.

Assuming that sewage transmission services are qualitatively homogeneous, a production function for them can be derived from engineering principles. Where management, as an independent variable, is relatively unimportant, engineering production functions have an advantage over production functions derived from ex post statistical information. For all relevant variables are easily identified and are precisely defined, and there is no problem of incorporating new technology as it comes along (Hirsch, 1970). This procedure is followed in Chapter III for the production function for sewage transmission systems.

In the analysis of profit maximizing behaviour of competitive firms we can proceed from production functions, via cost functions, to supply schedules, and supply schedules can be aggregated to represent the market supply. But when (public) goods are provided by a monopolist the marginal cost of output curve is <u>not</u> the monopolists supply curve. Under perfect competition one can define a unique supply price for each quantity offered. In monopoly, supply price is not unique. A given quantity would be supplied at different prices, depending upon market demand and marginal revenue (Ferguson, 1966, p. 237). All that we can say about the marginal cost curve of a monopolist is that it reflects the production characteristics of the firm.

When smoothly increasing returns to scale exist in an industry it is not possible for the output to be priced equal to marginal cost and for the firm to make a normal profit. In such a situation a decentralised price system cannot be relied upon to produce efficient resource allocation and collective intervention may be justified. The traditional theoretical solution for pricing with decreasing costs has been to price the good equal to marginal cost, in order that consumers make rational expenditures, and to cover the deficit by a tax unrelated to the consumption of the good (Vickrey, 1969). Thus for a monopolist, in this case a single public agency supplying sewage transmission, although the marginal cost curve is not the supply schedule, under conditions of decreasing cost, for the sake of efficient allocation in consumption, it becomes the supply schedule.

The Demand for Public Goods

Despite the fact that competitive market organization appears to have acquired normative significance beyond its analytic significance, it is in fact a part of a positive theory. If the positive-normative separation is hard to maintain in the private market, it becomes even more difficult in the public "market". Wicksell showed that only a unanimous decision to provide a public good can be unambiguously classed as Pareto optimal. In recent years attempts to derive a positive theory of public goods have been made by economists and political scientists. No comprehensive theory has emerged, but some of the problems that characterise public goods have been identified.

In a competitive world of private goods the rational individual consumer equates the marginal rates of substitution between goods in consumption with the ratios of their prices. For an individual the average and marginal price of a good are identical, and are the same for all individuals. In equilibrium in the market all consumers equate their marginal rates of substitution between all pairs of goods with the ratio of their prices. For public goods each consumer receives the identical quantity of output and it is the ratio of the <u>sum</u> of the marginal rates of substitutes for public goods in consumption that are equal to the price ratio. Private goods are therefore divisible and public goods are indivisible. For a private good the unit produced is the unit individually consumed, but for a public good the unit produced is simultaneously available to all consumers. In equilibrium the marginal conditions for efficiency in consumption in private and public markets are not the same (Samuelson, 1954).

To derive a conventional demand schedule for a public good may be appropriate when price signals are strong, when the output is measurable, when no significant externalities are associated with the good in production or consumption, or when close private substitutes are available for the good. Yet it is difficult to demonstrate a relationship between an individual's demand for a public good and his willingness to pay taxes.

James Buchanan has attempted to derive the "demand" for public goods using the marginal evaluation curve technique developed by Hicks in his investigations of consumer's surplus (Buchanan, 1968, p. 39-43). A marginal evaluation curve plots the slopes of successive indifference curves as they are intersected by an opportunity curve for different quantities of the public good. For each opportunity curve there is a unique marginal evaluation curve. The marginal evaluation curve is not analogous to a demand curve, but it does indicate the equilibrium quantities of public good an individual will take at a given price (see Figure 2.4).

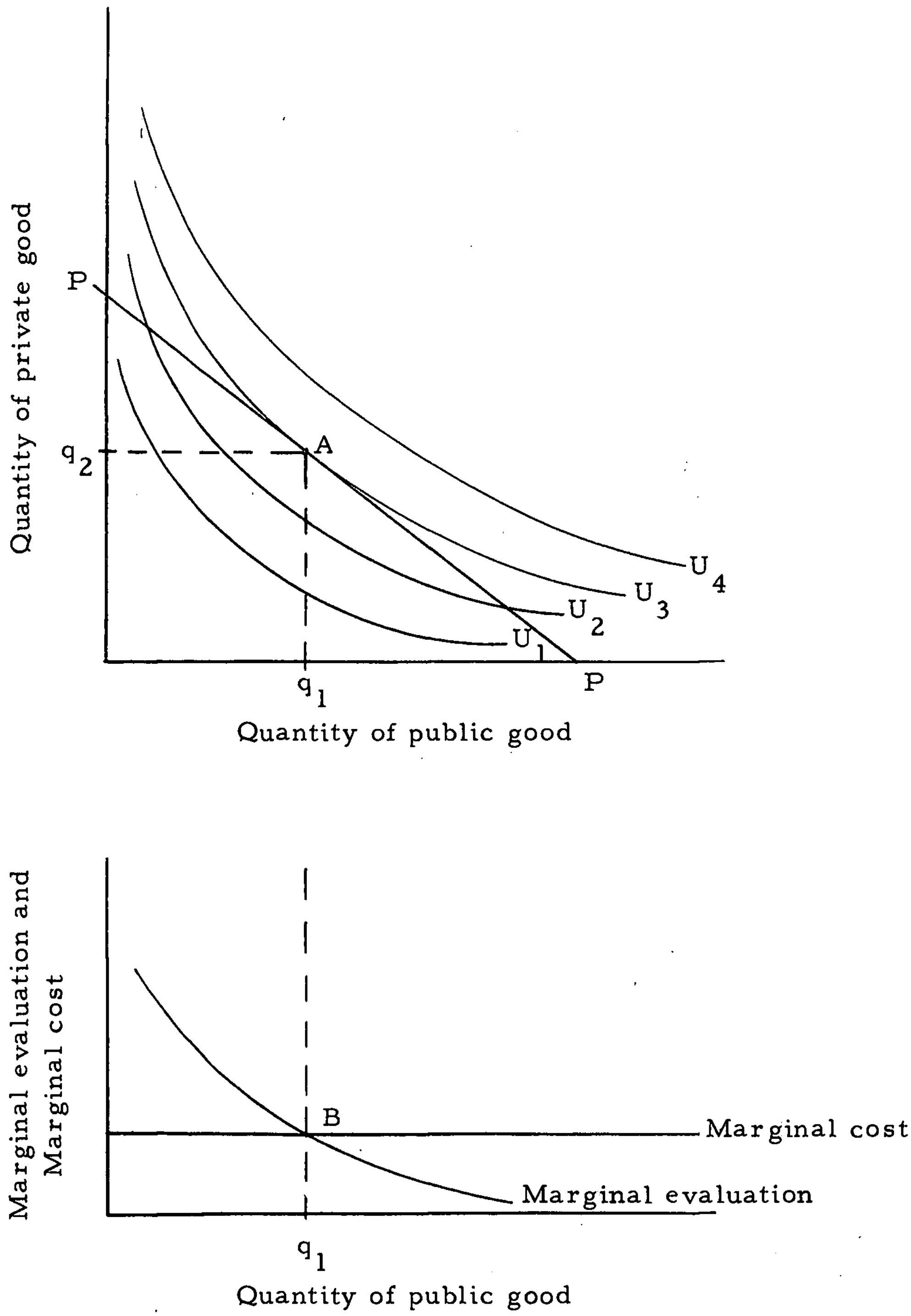


Figure 2.4. The determination of the optimum quantity of a public good in consumption using the marginal evaluation technique.

The equilibrium quantities of public and private good are determined at A, where the straight line opportunity locus PP is tangent to the indifference curve U_3, and at B where the marginal evaluation, ME, and marginal cost, MC, are equal. If the opportunity locus is non-linear, then the marginal cost curve is also non-linear. The ME curve does not say how much an individual would purchase at any other price offer. Nor can the individual equilibrium quantities be aggregated unless marginal and average cost of the public good are equal (as in the case for a private good in a competitive market). Thus this approach to estimating the demand for public goods, based on individual preference, breaks down.

We can conclude that, in order to achieve the necessary condition for the maximum net benefits criterion (that marginal project benefit equal to marginal project cost, of $V_i = dC_i/dN_i$), we can estimate C_i and N_i more easily than V_i.

A Political-Economic Solution

There are therefore, two serious objections to the maximum net benefits criterion; firstly, how to deal with non-efficiency objectives (equity, the environment, and the well-being of people), and secondly, how to estimate the demand for public goods in order to measure V_i, the value of an incremental unit of project output? (There are, of course, problems of evaluation other than these. For example there are problems of irreversibility [Wantrup, 1952, p. 39], option demand [Weisbrod, 1964], the evaluation of dynamic benefits and costs, and the fact that alternatives facing a decision-maker are discrete, not continuous, and often incommensurable, [Freeman, 1970]). Despite Mishan's warning that political processes can fail, on grounds of efficiency, ethics, and consistency, a combined political-economic procedure may be appropriate for solving problems of public choice.

"New political economy" is the name given to the emerging study of collective choice, which seeks to discover rational principles of group decision-making in order to guide public policy. Important individual works in the development of the new political economy are the writings of Anthony Downs (1957), Duncan Black (1958), James Buchanan and Gordon Tullock (1962), Mancur Olson (1965), and R. L. Wade and L. L. Curry (1968, 1970). An overview and summary of much of this work can be found in William Mitchell (1968), and an application of the models derived in this literature is provided by Robert Bish (1971).

The major contribution of these and related works appears to be the derivation of rules for rational collective choice. This approach could be valuable in choosing between alternative resource development projects when the maximization of net benefits is non-operational. Consider a community faced with a choice between alternative sewage transmission projects. Associated with each alternative is a vector of characteristics, each of which is considered to be relevant to the community as a whole. The vector of characteristics would include monetary benefits and costs, income redistributional effects, environmental effects, and any other measurable project effect that the community considers to be significant. A community wide election could determine what is preferred from the array of feasible alternatives. Individual preference is expressed in a democratic voting process. Wade and Curry identify fourteen necessary conditions for voting in a democracy. Three of these are particularly important to the procedure proposed here. First, "alternatives before the voter must be genuine and presented simultaneously"; second, "a device must exist to insure that important matters will appear on the ballot"; and third, "both costs and benefits of the voting choices must be known at the time of voting" (Wade and Curry, 1970, p. 57-58). These conditions are essential if the choice is to be made among feasible alternatives, and if the voter (decision-maker) is to be as fully informed as possible prior to the decision.

This democratic choice procedure is based upon rational, self-interested individualism. Each individual is assumed to seek a particular combination private and public benefits. More benefits are preferred to less benefits, and each citizen attempts to minimize the costs of the benefits he receives. Even though individual utility functions are independent, every individual must accept the pattern of benefits articulated by a democratic collective decision. If all the effects of a resource development project could be measured in commensurable terms (preferably monetary terms), and we assume individual rationality and a constant marginal utility of income between individuals, then a benefit-cost analysis that maximizes the present value of expected net benefits and the democratic voting procedure would be identical. In reality the voting procedure has value because the measurement problem has not been overcome. For example, in a choice between alternative water resource development projects, the monetary benefits and costs may be clearly defined, but the environmental effects may be hard to define in any terms, or at least impossible to evaluate on monetary terms. A voting procedure permits choice between alternative projects on the basis of all project effects.

Table 2.1. Hypothetical array of characteristics of alternative resource development projects.

Effects	A	B	--	X
Benefits	A_1	B_1	--	X_1
Costs	A_2	B_2	--	X_2
Environment	A_3	B_3	--	X_3
Redistribution	A_4	B_4	--	X_4
--	--	--	--	--
--	--	--	--	--
Other	A_n	B_n	--	X_n

THE PRODUCTION, COST, AND VALUE OF SEWAGE TRANSMISSION SERVICES

The purposes of this chapter are to investigate the production, cost, and value of sewage transmission services. First, a production function is defined, it is based on engineering data and relationships, and incorporates the most recent technology. The production function is generalised and represents production under average conditions of climate, soils, topography, drainage, infiltration and per capita sewage production. Second, a total cost function is defined. Cost data are derived from the average of the four lowest bids submitted on each of 35 major sewer schemes in Oregon, Washington, Idaho, and California constructed between 1965 and 1971. All costs are reported in constant dollars.(Appendix Table 2). Finally, in the third section, a report is made of an attempt to estimate the value that accrues to urbanising land from the public investment of sewer services in that land.

A Production Function for Sewage Transmission

Main sewers are usually required by state law to be designed to meet the expected peak flow either 25, or 50 years in the future. Civil engineers frequently design main sewers to meet the peak flow of the expected saturation population of an area, even if this means a design period in excess of 50 years. The design flow is dependent largely upon the design period; the expected population at the end of the design period; the size of the tributary area; the estimated average per capita daily rate of flow of sewage; the estimated peak flow (see Appendix Figure 1); and the expected groundwater infiltration. For example:

Design period	=	50 years
Expected population	=	10,000
Tributary area	=	500 acres
Ave. per capita discharge	=	100 gallons per day
Total discharge	=	1,000,000 gallons per day
Peak factor	=	1.8 (see Appendix Figure 1)
Peak flow	=	1,800,000 gallons per day
Infiltration rate	=	1,600 gallons per acre per day
Total infiltration	=	800,000 gallons per day
Design capacity	=	2,600,000 gallons per day

Appendix Table 1 defines a range of values for design capacity, under average conditions, for tributary areas of increasing size (500-7,000 acres), and for increasing population density (1-100 persons per acre). Appendix Table 1 assumes an average per capita sewage discharge of 100 gallons per day, and a peak/average daily flow ratio as defined in Appendix Figure 1. Infiltration is assumed to occur at the rate of 200 gallons per capita per day, or 1600 gallons per acre per day, whichever is the smaller (American Society of Civil Engineers and the Water Pollution Control Federation, 1969).

Using the data in Appendix Table 1, a production function for sewage transmission was defined using two alternative models. The generalised form of the first model was

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \epsilon$$

where the parameter estimates represent the marginal physical productivities of the inputs, X_1 and X_2, and where the negative of the ratio of the parameter estimates represents the marginal rates of substitution between the inputs. In this case the dependent variable is sewer system capacity, and the independent variables are not factor inputs but are the size of the drainage basin (X_1) and the population density (X_2). Therefore the parameter estimates represent the addition to total capacity attributable to the addition of one unit of area (β_1), and to the addition of one unit of population density (β_2). The ratio of the parameter estimates measures the number of units of density that must be given up per unit of area gained for a given quantity of system capacity.

The second model was a power function

$$Y = \beta_0 X_1^{\beta_1} X_2^{\beta_2} \epsilon$$

which when transformed becomes

$$\ln Y = \ln\beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \epsilon$$

which is linear in the parameters. In the second model the parameter estimates, β_1 and β_2, are the elasticities of production, which for this model are constants, and which indicate the percentage change in system capacity for a percentage change in drainage basin area or population density. The sum of the elasticities of production indicates the nature of the returns to scale, that is, if drainage basin area and population density are increased system capacity must increase in the same, or a greater, or a lesser proportion. The second model was fitted in addition to the first model since a graphic plot of the data indicated that there was continuous decreasing marginal productivity for both "inputs", area and population density.

For both models

Y = Design capacity, gallons per day.

X_1 = Size of the tributary area, acres.

X_2 = Population density, persons per acre.

β_i = Coefficient of X_i

ϵ = A random error.

Model 1.

$$Y = -15{,}545{,}156 + 5{,}810\ X_1 + 559{,}870\ X_2$$
$$(439)^{*} \qquad (28{,}934)^{**}$$
$$R^2 = 0.834$$

Model 2.

$$\ln Y = 1716.28 + 0.9661 \ln X_1 + 0.4767 \ln X_2$$
$$(0.0272)^{***} \qquad (0.0152)^{***}$$
$$R^2 = 0.954$$

All the parameter estimates were significant. The numbers in parentheses are the standard errors of regression. Model 2 provided the best fitting equation, with a higher multiple correlation coefficient and t-values of greater significance than model 1.

* = significant at the 5.0 percent level.

** = significant at the 1.0 percent level.

*** = significant at the 0.1 percent level.

For Model 1, β_1 is 5,810 gallons per day, and this is the addition to system capacity from a one acre increase in drainage basin area. β_2 is 559,870 gallons per day, and this is the addition to system capacity from a one unit increase in population density.

For model 2, β_1 is 0.9661, and β_2 is 0.4767, which are the percentage increases in system capacity for a percentage increase in area and population density respectively. For a percentage increase in area, capacity increases by an almost equal amount. For a percentage increase in density, capacity increases by less than half this amount. The sum of the parameters is greater than unity ($\beta_1 + \beta_2 = 1.4428$) indicating that for a percentage increase in both area and density, system capacity must increase by greater than one percent.

A Cost Function for Sewage Transmission

The relationship of sewer system capacity to total cost is defined by a cost function. The data for the cost function are found in Appendix Table 3. The procedure for generating these data was first, to translate the design capacity into sewer pipe diameter, and then to convert the pipe requirements into costs per linear foot. Assuming a minimum velocity of flow in the pipe of 2.5 feet per second, in order for the pipe to be self-cleaning, and a roughness coefficient of $n = 0.013$, pipe diameter is a function of sewage discharge and can be solved for using an alignment chart (see Appendix Figure 2). The cost per linear foot of pipe of increasing diameter was found by taking the average of the four lowest bids submitted on each of 35 major sewer schemes in Oregon, Washington, Idaho and California constructed between 1965 and 1971 (Appendix Table 2).

To define the cost function, the form of the statistical model used was

$$Y = \beta_0 + \beta_1 X_1 + \epsilon$$

where

Y = Total system cost, dollars.

X_1 = Design capacity, gallons per day.

β_i = Coefficient of X_i.

ϵ = A random error.

Using simple least-squares estimation

$$Y = -43,213 + 0.0230\ X_1$$

$$(0.0008)^{**} \quad R^2 = 0.87$$

The parameter β_1 was significant at the 1.0 percent level. Plotting the residuals against the predicted value of Y showed that the model was inadequate, and a better fitting equation would include the square of the independent variable, X_1. So the model was rerun, regressing Y against X^2.

$$Y = \beta_0 + \beta_1 X_1^2 + \epsilon$$

using simple least-squares estimation

$$Y = -1.1526 + 0.8416 X_1^2$$

$$(0.0250)^{***} \quad R^2 = 0.914$$

The parameter estimate β_1 was significant at the 0.1 percent level, and the plot of the residuals against the predicted value of Y appeared normal. The form of the cost function, where total system cost is a function of the square of system capacity has one significant implication. It implies that the average cost of the system is increasing, and consequently marginal cost is increasing and is greater than or equal to average cost. For the system as a whole, a price equal to marginal cost would yield sufficient revenue to cover total cost. Thus sewage transmission would not appear to be a natural monopoly, instead production appears to take place under conditions of increasing cost.

However this analysis is misleading, since if system capacity is defined in household or per capita terms the average cost per household or per capita declines as system capacity increases per unit area served (see Appendix Table 4). If average cost is declining, marginal cost is less than average cost, and price equal to marginal cost would yield insufficient revenue to cover total cost. If a natural monopoly exists whenever a single producer of some good can serve an entire market at the lowest <u>per unit</u> cost, and the unit consumed is one connection to the sewage transmission system per capita or per household, then sewage transmission is a natural monopoly.

In a perfectly competitive market, a profit maximizing firm would be in equilibrium whenever

$$\frac{MP_{X_1}}{P_{X_1}} = \frac{MP_{X_2}}{P_{X_2}} = \frac{1}{MC_Q} = \frac{1}{P_Q}$$

where $Q = f(X_1, X_2)$

$MP_{X_i} = \partial Q / \partial X_i$, the marginal physical product of input i.

P_{X_i} = price of input i.

MC_Q = marginal cost of output Q.

P_Q = price of output Q.

With the information generated in the production and cost functions, and a knowledge of the price of sewage transmission (where price, P_Q, in this case, is defined as being equal to the average increment to the assessed value of an unbuilt residential lot in a plotted sub-division from the presence of main sewerage on that lot) it can be shown that for sub-basins of average size and population density (X_1 = 2000 acres, X_2 = 10 persons per acre)

$$\frac{MP_{X_1}}{P_{X_1}} < \frac{MP_{X_2}}{P_{X_2}} > \frac{1}{MC_Q} > \frac{1}{P_Q}$$

Given P_{X_1} and P_{X_2}, in order to combine area and population density efficiently, sewage transmission should be provided to sub-basins of smaller area and/or greater population density. Also, in order to produce the profit maximining level of output, the above inequalities suggest that both area and population density should be reduced. However this is erroneous, since sewage transmission is produced under conditions of decreasing cost, and as capacity is reduced marginal cost increases (and the inverse of marginal cost decreases), and the inequality ($MP_{X_i}/P_{X_i} > 1/MC_Q$) becomes greater. Also, as is shown subsequently, the price of sewage transmission, as defined above, is greater than the marginal cost of sewage transmission. In a perfectly competitive market, and with production under increasing costs, the profit maximizing level of output would be achieved by increasing production of sewage transmission. However, in this case production is subject to decreasing costs, and expanding output would cause the inequality ($1/MC_Q > 1/P_Q$) to increase. It is for these reasons that the criteria for efficient allocation of resources and for the profit maximizing level of output in a perfectly competitive market with production subject to increasing costs do not apply to sewage transmission.

The Cost of Distance

The cost of sewage transmission increases with distance. In order for sewers to be self-cleaning they must flow at a minimum velocity of 2.5 feet per second. Velocity is a function of sewer roughness, radius and slope. Velocity can be calculated from Manning's formula (American Society of Civil Engineers and the Water Pollution Control Foundation, 1969, p. 78).

$$V = \frac{1.49}{n} \cdot R^{2/3} \cdot S^{1/2} \text{ feet per second}$$

where

V = Velocity, feet per second.

n = Coefficient of roughness

R = Radius, inches.

S = Slope, feet per thousand feet.

Thus for pipe of a given roughness and radius, velocity becomes a function of slope. Assuming a land area that is generally flat, and a given slope, depth of burial increases as distance increases. Below 20 feet the costs of pipe burial increase so sharply that it is customary to install pumps, raise the sewage to the surface again, and allow it to fall under gravity again. As pipe diameter increases the slope necessary to maintain adequate self-cleaning velocity declines. For example a 12 inch diameter pipe requires a minimum fall of 3 feet per 1000 feet, and will fall 20 feet below the surface in 10.82 miles (Appendix Table 5). Pipe capacity is an increasing function of pipe diameter (Appendix Table 5), and pipe slope, and consequently depth of burial, is a decreasing function of pipe diameter. The implications of these relationships are, first, for settlements of a given size, the need for pumping increases with distance, and second, for a given distance, the need for pumping decreases with the size of the settlement served. Consequently, if a drainage sub-basin is developed for urban use at some distance from the site of sewage treatment, the need for pumping stations decreases as the population density of the settlement increases. Discontiguous low-density settlements have a higher requirement of pumping stations than do high-density settlements, other things being equal.

Using typical 1972 pumping station cost estimates (provided by Mr. Frederick Repp of the Cornell Manufacturing Company, Portland, Oregon) the capital cost of pumping stations, per unit, and per gallon per foot of linear distance was derived (Appendix Table 6). As sewer capacity increases the total cost of pumping stations increases, but the cost per gallon per unit distance decreases continuously. Thus for the example given in Appendix Table 6, capital cost of pumping stations per household decreases from $1012.09 for 12 inch mains, to $1.31 for 96 inch mains, for a residential development located 10 miles from the site of the treatment plant. For a development of a given size, pumping costs are a linearly increasing function of distance. For a given distance, pumping costs are a decreasing function of size, decreasing at a decreasing rate per unit of size (Appendix Table 6, column 3).

The Value of Sewage Transmission

In a free-enterprise economy prices transmit information to the owners of resources and to the users of resources. For the purpose of analysis, prices are determined by the interaction of supply and demand. The supply and price of sewage transmission however, are determined by institutional forces other than the market. But this does not mean that the price of sewage transmission could not be determined *as if* it were formed by the interaction of supply and demand. For economic theory is an organizing device as well as a set of substantive propositions (Friedman, 1962, p. 8). The marginal cost schedule of a firm producing sewage transmission can be derived from knowledge of the production function and the costs incurred by the firm. A demand schedule is infinitely more difficult to derive. Observations of price, income characteristics of consumers, and quantity of service consumed at a given price, and other potentially relevant variables are not available. Within a community main sewage transmission is either available, or not available, and there tends to be either a uniform price, or a zero price.

Attempts have been made to estimate statistical demand curves for municipal services. A recent example is a model of municipal water demand by Wong (1972). This study attempted to explain the relationship between price, income and average summer temperature, and the economic demand for municipal water. Unfortunately the study encountered problems of poor data, for prices and incomes, and an insufficiency of either time series or cross-sectional observations. The study was of value because few similar studies exist, and because Wong drew attention to the severity of the data limitations for researchers and policy-makers. Using a power function of the form

$$Y = \alpha X_1^{\beta_1} X_2^{\beta_2} \epsilon$$

which in logarithmic form becomes

$$\log Y = \log \alpha + \beta_1 \log X_1 + \beta_2 \log X_2 + \epsilon$$

and yields constant elasticities of production β_1, β_2, Wong estimated the elasticities using simple least-squares estimation for both time-series and cross-sectional data. These parameter estimates were found to be of either low significance, for cross-sectional data, and not significant for time series for price and income. Average summer temperature was found to be the major determinant of average per capita demand.

Sewage transmission service data are generally less complete than data for municipal water demand. In particular water is often individually metered and sewage is not, thus it is impossible to show how the quantity of sewage discharged by individuals varies with price. Because of this data problem, an alternative approach to estimating the value of sewage transmission services was used. Sewage transmission is a priming action in the process of converting rural land to urban use. It is a capital investment which differentiates land qualitatively. As the supply of improved land is generally fixed in the short-run, the investment earns a quasi-rent. Using a model with the basic statistical form

$$Y = \alpha + \Sigma\, b_c X_c + \Sigma\, b_o X_o + \epsilon$$

where

Y = Assessed land value

X_C = Cardinal independent variable

X_o = Ordinal independent variable

b = Regression coefficients of X_c, X_o

ϵ = A random error

an empirical investigation of the effect of sewage transmission on land value at the urban periphery was undertaken. The dependent variable was the assessed value of a single-family residential lot in a platted subdivision. The lots observed were unimproved or improved with the presence of main sewer and water services, but all lots were unbuilt. The land was all in the "ripening" stage between rural and urban residential use. It was considered that during this transitional stage the increment to land value from the provision of sanitary sewage to land could be more easily identified than after the lots were built.

Parameters of the following equation were estimated using simple least-squares estimating procedures:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \epsilon$$

The dependent variable, Y, is the 1972 assessed value of an unbuilt residential lot in a platted subdivision in Washington County, Oregon. Actual market value would have been preferable to assessed value, but there were too few true sales of platted lots (only 27 in 1971) to provide a valid sample. A study of the ratio of assessed to market value of all true sales of real property in the County in 1971 does reveal that the ratio follows approximately a normal distribution with a mean almost equal to one (see Appendix Figure 3). For the mean of the observations assessed and market value are equal, and the departures from the mean are normally distributed. Assessed value per lot ranged from 500 to 5500 dollars, with a mean of 2993 dollars.

X_1 is the size of the subdivision in terms of the number of lots in the subdivision. Some 85 subdivisions were platted in Washington County in 1971 ranging in size from 5 to 116 lots, with a mean of just over 22 lots per subdivision, and a total of 1875 lots.

X_2 is the approximate lot size in square feet, the product of the lot frontage and depth. Lot size ranged from 2, 400 to 60, 000 square feet, with a mean of 8, 667 square feet.

X_3 is a zero-one dummy variable indicating the presence (one) or absence (zero) of main sewer and main water to the lot. It is unfortunate that these two improvements, sewer and water, must be considered together. However in every case where main sewerage was provided main water was simultaneously present. Thus the effect of variable X_3 on the dependent variable is the combined effect of main sewer and water availability. Of the 85 subdivisions platted in 1971, 31 had access to main sewer and water service.

X_4 is the radial distance, measured in miles and tenths of a mile, from each subdivision to the central business district of the City of Portland. This distance ranged from 4. 0 to 21. 4 miles, with a mean of 9. 0 miles.

X_5 is the distance, measured in miles and tenths of a mile, from each subdivision to the nearest of any one of three major highways giving access to the central business district of the City of Portland. Values of X_5 ranged from zero to 2.6 miles, with a mean of 0.87 miles.

The variables X_1-X_5 were regressed against Y in two ways. Firstly all the data was included to give an overall regression. Following this the observations were stratified according to lot size into 4 groups, group A including all lots less than 6,000 square feet, group B all in the range 6,000 - 7,999 square feet, group C all in the range 8,000 - 9,999 square feet, and group D all lots of 10,000 square feet and larger. An outline map showing the location and frequency of the subdivisions platted in Washington County in 1971 is provided in Figure 3.1.

The results of these estimations are as follows. For the overall regression

$$Y = 2583 - \underset{(7.3269)}{7.0519}\, X_1 + \underset{(0.0198)^{***}}{0.0774}\, X_2 + \underset{(286.03)^{***}}{1363.72}\, X_3$$

$$- \underset{(36,1210)^{*}}{71.5116}\, X_4 + \underset{(0.3976)^{*}}{95.84}\, X_5 \qquad R^2 = .37$$

Variables X_2 and X_3 were significant at the 0.1 percent level. X_4 and X_5 were significant at the 5.0 percent level. X_1 was not

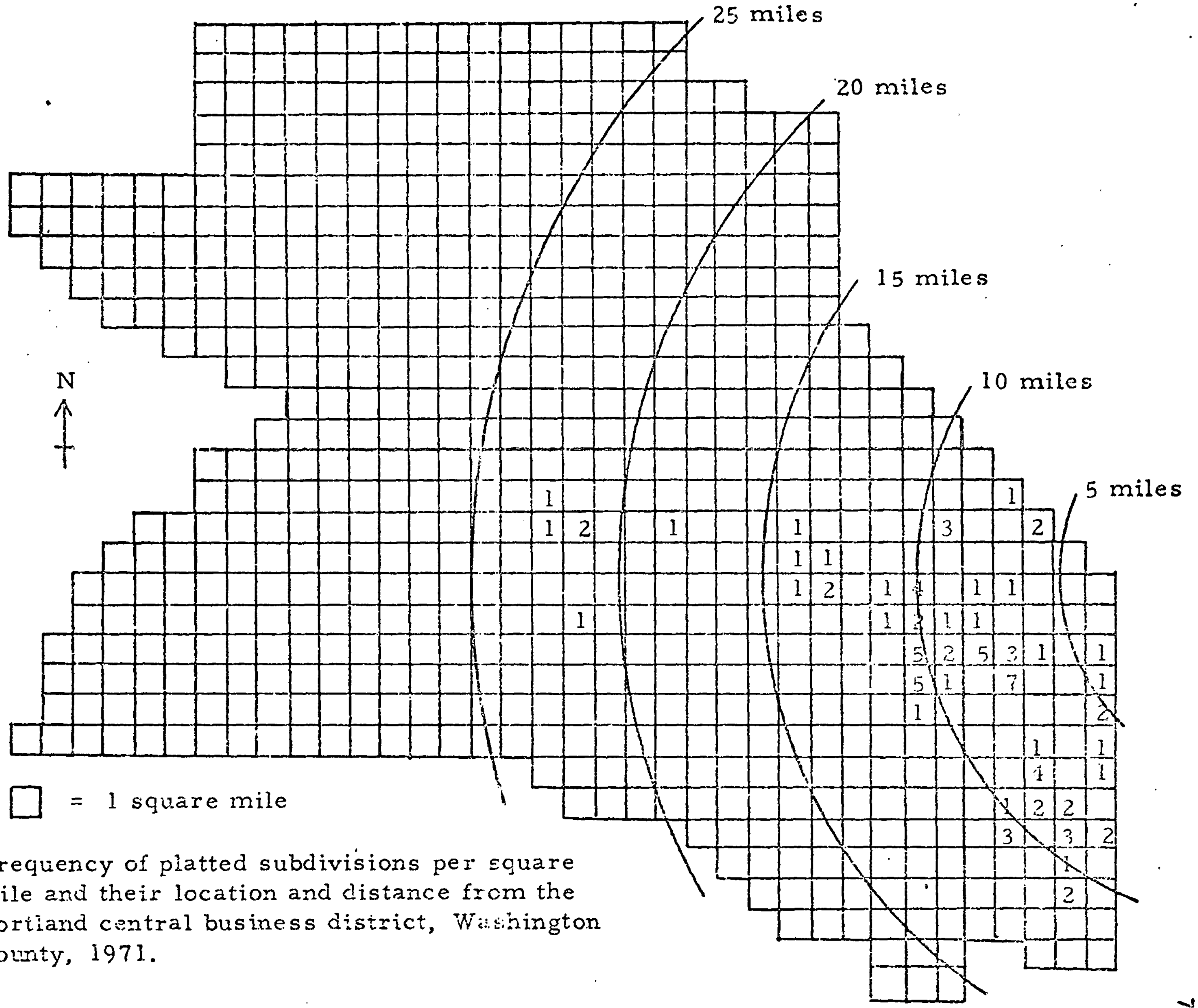


Figure 3.1. Frequency of platted subdivisions per square mile and their location and distance from the Portland central business district, Washington County, 1971.

significant. The coefficients β_2, β_3, and β_4 may be interpreted as saying that, as lot size increases by one square foot, assessed value increases by approximately 8 cents, and as distance from the central business district increases by one mile assessed value decreases by over 71 dollars, and that the availability of main sewer and water increases lot value by over 1363 dollars. The signs and magnitudes of the significant variables seem plausible. The low overall multiple correlation coefficient (R^2) is probably due to the incomplete specification of the equation, and in particular to the lack of variables designed to measure lot quality, such as the presence of trees on the lot, and the characteristics of the neighborhood. Overall the regression was significant at the 5 percent level with 5 and 81 degrees of freedom.

When the lots were stratified according to lot size the results were as follows.

Group A

$$Y = -1233 - \underset{(15.9579)}{17.6502\, X_1} + \underset{(0.3656)^{*}}{0.4833\, X_2} + \underset{(371.82)}{373.61\, X_3}$$

$$+ \underset{(91.61)^{**}}{217.40\, X_4} + \underset{(62.94}{158.42\, X_5} \qquad R^2 = 0.68$$

Group B

$$Y = 2345 - 12.2101 X_1 + 0.5708 X_2 + 1482.47 X_3$$
$$(8.5372)^{*} \quad (0.5333) \quad (447.36)^{***}$$
$$- 103.02 X_4 - 513.13 X_5$$
$$(86.96) \quad (409.94) \qquad R^2 = 0.44$$

Group C

$$Y = 2707 - 1.4233 X_1 + 0.0734 X_2 + 1743.31 X_3$$
$$(2.0775) \quad (0.0686) \quad (608.45)^{***}$$
$$- 99.82 X_4 + 277.89 X_5$$
$$(67.80)^{*} \quad (483.09) \qquad R^2 = 0.35$$

Group D

$$Y = 1786 - 40.3961 X_1 + 0.08613 X_2 + 353.64 X_3$$
$$(124.4439) \quad (0.07423) \quad (3794.01)$$
$$- 81.49 X_4 + 757.24 X_5$$
$$(147.22) \quad (1024.43) \qquad R^2 = 0.84$$

The stratification into 4 groups, A-D, produced some rather erratic results. Compared with the overall regression the significance of the parameter estimates fell, and for some parameters the sign changed. But in all groups but group C the R^2 increased. For the purposes of this research the single most important parameter is β_3. This represents the average increment to Y from the presence of main sewer and water. These values were

		$
Overall	=	1363.72
Group A	=	373.61
Group B	=	1482.47
Group C	=	1743.31
Group D	=	353.64

The value of main sewer and water to the lot appears to increase with lot size. The low value for group D may be explained by the fact that the average lot size for group D is 19,810 square feet, which would put these lots into a local zoning class where private septic tanks for sewage disposal are still permitted when main water is provided. Thus the availability of main sewage may be of lesser value to the lots in this group.

As would be expected as lot size increases the average distance of the lots from the central business district of Portland increases, and the average distance of the lots from a major access highway increases. But the signs of the parameters β_4, β_5 changes. A priori location theory would lead one to expect the sign of β_4 to be negative, lot value decreasing with distance from the central business district. One would expect β_5 to be positive, the close presence of a major freeway having a negative effect on lot values. With only two exceptions the results are consistent with what one would hypothesise a priori.

Table 3.1. Mean values of radial distance from central business district, X_4, and distance from major access highway, X_5, and the signs of the estimated parameters.

	Mean X_4 miles	Mean X_5 miles	β_4	β_5
Overall	9.04	0.87	-	+
A < 6,000 square feet	7.41	0.65	+	+
B 6,000-7,999 square feet	8.97	0.78	-	-
C 8,000-9,999 square feet	9.37	1.00	-	+
D > 10,000 square feet	10.68	1.14	-	+

If we can assume that at least half the increment by β_4 is due to the availability of a main sewer, then the value of the average lot is increased by over $680.00. As lot size increases, the population density declines, the increment of value to the average lot increases, using the results of groups A-C only:

Table 3.2 Population density and average increment to land value from availability of sewage transmission.

Group	Population density persons per acre	Increment to land value from availability of sewage transmission
A < 6,000 square feet	23.74	$186.81
B 6,000-7,999 square feet	11.71	$741.24
C 8,000-9,999 square feet	9.11	$871.66

Which implies that the increments to land value per acre are $1385.90, $2712.48 and $2481.51 respectively. If these observations of density and increment to land value per acre were points on a demand curve, then these results would imply that the absolute value of the price elasticity of demand for sewer service to large lots (Group C) is greater than one, and for small lots (Group A) in less than one.

Summary of Costs and Values of Sewage Transmission

The average total cost of sanitary sewage transmission per capita, or per household, is continuously decreasing as population density increases. For a given density, average total cost remains approximately constant as drainage basin area increases. Cost declines from a maximum of $274.50 per household, for a population density of 1 person per acre, to a minimum of $6.11 per household, for a population density of 100 persons per acre, in a 500 acre drainage basin.

The average increment to lot value from the provision of sanitary sewage transmission was estimated as somewhere in the range $186.81 - 871.66, incremental value increasing as population density declines from 23.74 to 9.11 persons per acre. Comparing the incremental values generated with the direct costs of the service provided, for all instances the benefits exceed the costs by a factor of 10-20.

Some of the incremental value may be due to the joint provision, with transmission, of sewage treatment capacity. However, the capital costs of treatment generally account for less than 40% of the total cost of a complete sanitary sewer system that includes sewage transmission, and primary, secondary, and tertiary treatment.[2/] Even if the incremental values of the provision of sewage transmission are reduced by 40%, they still exceed the costs by a factor of 5-13. The implications of the divergence between values created by, and costs of publicly provided urban services for project appraisal and pricing policy is discussed in detail in Chapters 4 and 5.

[2/] This information was obtained in a private communication from Mr. Charles Bayles, senior estimator for Cornell, Howland, Hayes, Merryfield and Hill, Inc., Corvallis, Oregon, 1972.

Table 3.3. Comparison of incremental value and average cost of sewage transmission per household.

Population density	Incremental value	Population density	Average cost
23.74	$186.81	25	$18.43
11.71	$741.24	10	$34.14
9.11	$871.66	5	$55.74

ALTERNATIVE SEWAGE TRANSMISSION SYSTEMS

In this chapter the costs, benefits, and other effects of alternative sewage transmission systems for the study area, defined in Chapter I, are reported and compared. This empirical application of the information generated in Chapter III proceeds as follows. First, the land area, the Tualatin River Basin, is defined and subdivided into the basic spatial units necessary for planning sewage transmission. These basic units are the minor drainage basins, or sub-basins, of the principal tributaries of the Tualatin River. Second, the base period (1970) population of the study area is defined, and the population distribution among the sub-basins is described. Third, assuming a given rate of population increase and a planning horizon of 30 years, alternative sewage transmission systems are proposed. These are chosen to represent different degrees of urban containment. Fourth, and finally, the costs, benefits and other effects of the alternative systems are compared.

The Tualatin River Basin

The Tualatin River Basin covers approximately 730 square miles, and is located almost entirely within the boundaries of Washington County, Oregon. For simplicity and compatability of data, this study focuses only on the area of the basin located within

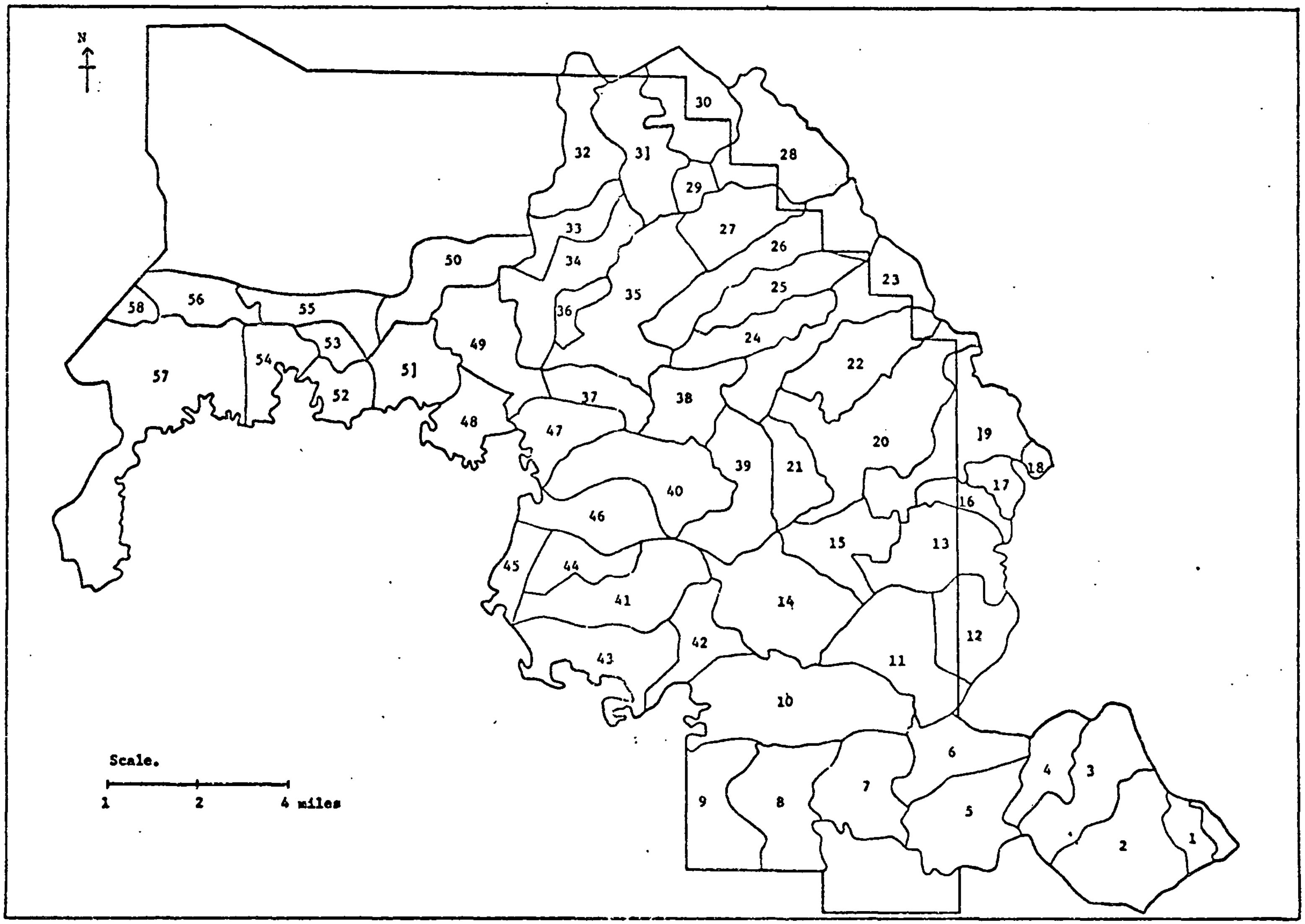
Washington County. Small portions of the basin are located within Multnomah and Clackamas Counties, and they do fall within the jurisdiction of the Unified Sewerage Agency of Washington County, but in all other respects they are administered by their own county and local governments.

The Tualatin River drains most of Washington County as it flows from its source in the Coast Range to its confluence with the Willamette River, some 90 miles away. Fifteen major creeks, each with its own minor tributaries, flow into the Tualatin. In all, the basin may be divided into 58 sub-basins (see Figure 4. 1), and 52 of these are located entirely or partially within the study area. Details of sub-basin size are found in Appendix Table 8. Within Washington County the sub-basins total 118, 191 acres. They range in size from 205 to 6957 acres, with a mean of 2273 acres. Thirty-five of the sub-basins fall within 1501-3500 acres. The area of the drainage basins was measured by the author using a planimeter, and therefore there is a possibility of errors in the measurement. But if errors are present they are likely to be small, probably less than one percent.

Population in the Study Area

The U.S. Department of Commerce, Bureau of the Census, decennial census of 1970 provides the base period estimate of the

Figure 4.1 Minor drainage basins of the Tualatin River Basin.



study area population. The total population of Washington County was estimated to be 157,920 spread over approximately 467,200 acres. The 1970 population of the study area was estimated as 141,930 (approximately 90% of the county total), spread over an area of 118,191 acres. The study area population was unevenly distributed among 52 sub-basins. The population of individual sub-basins ranged from 77 to 21,675, with a mean population of 2729. The overall population density was 1.19 persons per acre, with a range from 0.27 to 4.50 persons per acre. The population density of actual urban residential neighborhoods is of course much higher than this. The most recent detailed study of population, made in 1967, counted 137,000 people living on 20,500 acres of urban land. That is, there was a mean urban residential density of 6.7 persons per acre, with a range from 4.4 to 31.3 persons per acre within individual census tracts (Stephens, Thompson and Runyan, 1969, p. 30). These estimates of urban population densities included an allowance for public urban spaces and services, such as highways and sidewalks, parks, schools, and other public buildings.

Almost any comparison of these figures with other urban areas in the U.S. reveals that the population densities throughout urban Washington County are very low. A significant contributory factor to this situation must be the lack of sanitary sewers in the rural areas, which forces individual residents to seek homesites large enough to legally, and physically, accomodate on-site sanitary sewage disposal systems.

If the 1970 study area population, defined according to census tracts, is redistributed among the basins of the Tualatin River drainage, the estimated population distribution is as reported in Appendix Table 8. In order to design sanitary sewer systems to meet current and future needs the expected population growth of an area must be forecast. For transmission systems with a design period of from 25 to 50 or more years, long-term forecasts are required. The design period is the number of years for which the proposed system is economically or structurally adequate. Populations increase or decrease as birth, deaths, immigration, and annexation proceed. Each of these elements is influenced by social and economic factors which may, or may not, be predictable with any fair degree of accuracy. Long-term population forecasts are consequently difficult to make, are in need of periodic revision in the light of new social and economic phenomena, and may also possess power to be self-fulfilling once they are made. Yet despite this uncertainty, long-term forecasts must be made, and are made, for the design period of major public works structures.

A population projection for the study area was made by the consulting engineers on the master plan (Stephens, Thompson and Runyan, 1969, p. 32). Washington County population was forecast to expand to 353,000 by the year 2000. This represents an increase of 195,080 persons over a 30 year period, or an average annual increase of 4.12%. In the master plan the additional population was distributed among the census tracts in accordance with the anticipated land use, and in accordance with the planner's conception of what constitutes the maximum acceptable population density within each census tract. This is where the power to determine future land use patterns is born. The saturation population of an area is governed by the ability of the essential services to function adequately, and the upper limit of service capacity is determined by the planner's concept of what an acceptable saturation population is. It is in this way that the long-term forecast of population for an area has the power to become self-fulfilling.

The comparison of alternative transmission systems which follows in this chapter is based upon the population projection found in the master plan. The projected year 2000 population of 353,000 is accepted, but the population distribution implicit in the master plan is not accepted. In fact a primary objective of the comparison of alternatives is to calculate the effects of alternative population distributions. Population distribution and density is assumed to be a variable and not a parameter. As was shown in Chapter III, different population densities are associated with different levels of cost, and with different levels of benefit accruing to land from the provision of sewage transmission services. If a rational choice is to be made by the residents of the Tualatin River Basin when they allocate scarce resources to meet their sewer service needs, then the effects of alternative means to those ends should be understood prior to any decision. It is not the prerogative of the civil engineer or the professional planner to determine, even implicitly, the future land use pattern of an area by providing urban public systems which satisfy only their criteria of engineering efficiency and their preconceptions of how and where residential growth should occur. On the other hand it would be practically impossible and needlessly confusing to present all possible alternative solutions to such a complex problem. However, a number of genuine alternatives, which meet, to a greater or lesser degree, the objectives considered to be relevant by the decision maker, should be presented simultaneously. In the next section two alternatives are examined in detail. They are both conjectural, and represent what might be considered as extremes.

In the first proposal the population of the study area is expected to grow in accordance with the projection in the master plan. However, population is assumed to grow in proportion with the 1970 population. The rate of population growth in the most sparsely populated area is assumed to be identical to that in the suburban population centers. Experience and growth theory would both suggest that this is an unlikely event. But it is one which implies no containment of suburban expansion into rural areas, and results in a dispersed, low-density suburban fringe to the Portland metropolitan area.

In the second proposal an opposite extreme situation is considered. All future population growth is restricted to take place within the 6 sub-basins which contain the 4 primary urban places in the study area, the cities of Beaverton, Hillsboro, Forest Grove and Tigard. Outside these 6 sub-basins the 1970 population is assumed to remain stable. Again, this may be criticised as an improbable event, but it provides an informative exercise and some valuable contrasts with the first proposal, and with the existing master plan.

Transmission System - Proposal I

Proposal I is a conjectural sewage transmission system designed to represent an absence of suburban containment. Incremental population growth is distributed evenly throughout the population in proportion to the base period population. This means that rural, and primarily agricultural, sub-basins gain in population at the same rate as the existing urban centers. In fact this proposal is not as extreme as it might appear at first glance, for since 1950 much of the population growth has taken place within the rural unincorporated areas which are intermingled with the principal eastern and central Washington County communities. However the value of Proposal I rests in its ability to represent relatively uncontrolled suburban expansion.

In Proposal I the incremental population is equal to 211,070 persons. These are distributed among the 52 sub-basins in the study area in accordance with Appendix Table 8. In terms of population size and density the sub-basins remain in the same rank order contained in Appendix Table 8, but the populations now range in size from 192 to 53,909, and with population densities from 0.50 to 11.13 persons per acre.

In order to design a sewage transmission system it is necessary to define not only the location and size of the population, but also the location of the sewage treatment plants. If treated sewage is discharged into the waters that drain a river basin, the site of treatment plants becomes, in the main, a function of the effluent load and the capacity of the waters to accept the effluents without experiencing an unacceptable deterioration in water quality. Water quality is measured in terms of a number of parameters, such as pH, temperature, dissolved oxygen content, biological oxygen demand, coliform organisms, color, turbidity, total dissolved solids, and the presence of algae. Readings taken by the Oregon State Sanitary Authority and the Federal Water Pollution Control Administration, prior to the publication of the master plan in 1969, indicated that throughout the Tualatin River and its tributaries, and especially during the months of low flow, May-November, water quality is dangerously low. The large quantities of partially treated effluent are aesthetically objectionable, pose a threat to public health, and are progressively destroying the essential organisms of the aquatic environment which help to maintain the water quality.

Every body of water possesses a natural capacity to absorb some pollutants without suffering a permanent fall in water quality. Pollutants may be classified according to the effect they have on receiving water and, consequently, on water quality downstream. Nondegradable pollutants are stable substances which are not materially altered by natural biological processes in running water. These include many industrial and agricultural wastes. Most biological pollutants are degradable, including municipal effluents, Microorganisms in the aquatic environment decompose many degradable pollutants by oxidation to harmless, stable, end products. As long as the waste-assimilative capacity of water is not exceeded, this process of self-cleaning continues. The capacity to assimilate wastes in a function of the nature of the wastes and the hydrology of the stream, in particular, the volume and velocity of flow, the depth, turbulence, temperature, and the concentration of dissolved oxygen (DO). As long as DO concentration is high enough (greater than 5.0

milligrams per liter), bacteria can aerobically degrade most organic municipal effluents to harmless wastes. If DO concentration is inadequate, harmful by-products of anaerobic bacterial activity result.

Water temperature and DO concentration are the major determinants in the assimilation of degradable organic wastes. Every 10 degrees Fahrenheit rise in temperature produces a doubling of bacterial metabolic activity. But if temperature rises, or stream velocity falls, the quantity of available oxygen decreases. This results in a great reduction in the natural assimilative capacity of the Tualatin River during the high temperature-low-flow summer months.

Flowing waters are reoxygenated by reaeration at the waters surface and by the photo-synthetic activity of aquatic plant life. Typically the contribution from photosynthesis is slight. Consequently two important natural processes proceed simultaneously. There is oxygen removal by bacteria degrading pollutants, and there is surface reaeration. Both are functions of time and the characteristics of the stream-flow. Normally, when an oxygen demanding waste is released into a stream deoxygenation proceeds faster than reoxygenation, and an oxygen deficit results. As a stream flows, reoxygenation proceeds at a continuous rate, and the rate of deoxygenation decreases, and over time the oxygen deficit is made up. The form of the oxygen deficit can be approximated mathematically using a method pioneered by Streeter and Phelps (1946).

In the master plan an iterative analysis, assuming a minimum dissolved oxygen deficit of 6.0 milligrams per liter and water temperatures typical of the low-flow summer months, was performed to identify the natural waste assimilative capacity of different reaches of the Tualatin River. The study assumed different degrees of sewage treatment prior to the release of effluents into the Tualatin and its major tributaries. In all cases, even with uniform tertiary treatment throughout the basin, it was evident that low-flow augmentation was required. Assuming that supplementary water was available to dilute the effluents, 7 potential treatment plant sites were defined. (If low-flow augmentation was not available, then even with uniform tertiary treatment throughout the Tualatin basin, the natural assimilative capacity of the Tualatin River has already been exceeded.) These 7 locations were rechecked for suitability assuming the population distributions defined in Transmission System Proposals I and II, and were found to be satisfactory. That is, given the population distributions, and assuming tertiary treatment, sewage outfalls at these locations would produce no undesirable oxygen deficits. Six treatment plant sites are located on the main stream of the Tualatin River, none are on its tributaries. The seventh site is located on the Willamette River, to which the Tualatin is a tributary.

Given the size of the drainage sub-basins, the projected population and the location of the sewage treatment plants, it is possible to distribute the incremental population around the study area in different ways and assess the effects. Associated with each sub-basin there is a forecast population, which will discharge sewage into the system in proportion to the population size. In addition there is the volume of groundwater infiltration, which is a function of sub-basin area. Given the sewage discharge combined with the groundwater infiltration, allowance must be made for the expected peak daily flow (Appendix Figure 1). System capacity, in terms of main diameter, is a function of expected peak daily flow.

Also associated with each sub-basin is the length of main necessary to drain each sub-basin, and connect the sub-basin with the treatment plant. However, with the exception of sub-basin 54, the sub-basins are not independent, they are interconnected, as depicted in Appendix Figure 4. For example, consider 4(4). The wastewater discharged by sub-basin 46 flows through sub-basin 40 en route to the treatment plant located in sub-basin 47. Consequently the main capacity in sub-basin 40 must be sufficiently large to accomodate its own load plus that of sub-basin 46. And likewise sub-basin 47 must be capable of handling the total expected peak daily flow from all three sub-basins. Appendix Figures 4(6) and 4(7) are considerably more complex than this.

With a knowledge of increasing main pipe diameter, length of main, and cost per unit length (Appendix Table 2), it is possible to calculate the total cost of the system. For Proposal I the estimated total cost was found to be \$14, 535, 515.00. This represents a mean per capita cost of \$41.03, and a mean cost per household of \$131.30. (There was an average of 3.2 persons per household in Washington County in 1970.) However if the total investment is amortized over a 30 year period, with a discount rate of 7%, the annual cost of the investment becomes \$1, 248, 077.50. This represents a mean annual per capita cost of \$3.52, and a mean annual cost per household of \$11.27.

Associated with this level of costs are certain other effects. There is an overall population density of only 3.00 persons per acre spread across more than 118,000 acres. The urban area of Washington County consequently increases from 20,500, unconsolidated acres to a consolidated low density zone nearly 6 times as large. This expanded urban area comes largely at the expense of agricultural acreage which is reduced from 120,000 acres to 52,000, equal to a loss of 2233 acres of harvested cropland per year. Within the enlarged urban area actual neighborhood population densities are not defined, for these are private location decisions. But neighborhood densities are in general likely to be higher than 3.00 persons per acre. For in residential areas approximately 30-40%

of the land surface is used for public open spaces, such as highways and schools, and in Washington County 0.44 acres of urban land are typically developed for commercial use per 100 population.

In Chapter III an attempt was made to estimate the incremental value to otherwise unimproved land from the provision of main sewer service. From the overall regression the average improvement in value to an average lot of 8,667 square feet was found to be $1363.72. If we can assume that at least half the increment is due solely to the availability of a main sewer, then the value of the average lot is increased by over $680.00. Assuming that 30% of urban residential land is used for public purposes, and that there are 3.2 persons per household, and there is one household per lot, lots of 8,667 square feet represent an average population density of 11.26 persons per acre. This is a considerably greater population density than that in Proposal I. If $680.00 per lot is a reliable estimate of the value of the presence of main sewer service to a residential lot of 8,667 square feet, this represents a value of $2392.36 per acre. Invested for 30 years at 7% (to be comparable with the cost calculations above), the present value of the total gross value created is $19,015,675.00, which represents $53.68 per capita, or $171.78 per household per annum.

If we can assume that the above calculations of value created and investment cost represent the gross, direct benefits and costs of Proposal I, then we can state that considerable direct net benefits are created. These are equal to $17,767,668 with a gross, direct benefit-cost ratio of 15.2. But calculations such as this are over-simplified. For example, Proposal I is a specifically regional project. The regional benefits are probably equal to the national benefits, however, the costs may be shared nationally, and federal agencies may offer less expensive financing arrangements than can be obtained regionally. A second problem may be that prices change over time. There may be changes in the general level of prices, and there may be changes in the price of particular project inputs and outputs relative to the general level of prices. If the future trend in costs and value of sewage transmission services were understood then adjustments in the benefit-cost calculation could be made directly or via the discount rate. A third problem that has been ignored is the staging problem. If a community service needs expansion to meet demands placed on it by future populations, then the expansion need not be made all at once, but can proceed in stages as the need increases. The cost calculations above assume that a single all-or-nothing decision is made to expand capacity in time period 1 to meet the need imposed in time period 30. But idle capacity yields no benefits. If demand for project outputs grow over time, the more a project is deferred, the more quickly it will be used to capacity, and the greater will be the benefits generated per unit time of project life (Howe, 1971, p. 88). At the same time the present value of project benefits falls as the project is deferred further into the future. The optimum time of construction maximizes the net present value of a project, but to calculate this requires specification of the growth in demand for project output. For a given area the quantitative growth in demand for sewage transmission must be forecast at the outset. So why cannot the project be staged, one sub-basin at a time? The main problems are that individuals are free to locate homes wherever they like, provided they act within the law, and sub-basins are interdependent. Consider a decision to expand population in sub-basin 20, in Appendix Figure 4(7). The implications of that decision are felt throughout the 13 associated sub-basins. Consequently, it is necessary to develop the sub-basins jointly in order to avoid the generation of externalities from one sub-basin or another.

Transmission System - Proposal II

Proposal II is also a conjectural sewage transmission system, designed to represent a policy of suburban containment. Incremental population growth is restricted to the 6 drainage sub-basins which contain the existing (1970) urban centers. These urban centers are the communities of Beaverton, Hillsboro, Forest Grove and Tigard, and they are contained within sub-basins 20 and 22, 49 and 51, 57 and 11 respectively. The total 1970 population of these four principal communities was 46,829, or approximately 34% of the population of the county. The total 1970 population of the six sub-basins containing these communities was 53,496, because in addition to the four incorporated areas, the sub-basins contained additional population located in adjacent un-incorporated areas. The forecast population increase for the study area by the year 2000 is 211,070. If the additional population is distributed among the 6 sub-basins in proportion to their acreages, then the population change is as shown in Table 4.1.

Table 4.1. Land and population changes, Proposal II.

Sub-basin	Area acres	Population 1970	Population 2000	Population density, persons per acre (2000)
11	3290	4966	36416	11.07
20, 22	7507	30565	102325	13.63
49, 51	4327	8994	50355	11.64
57	6957	9011	75513	10.85
	22081	53496	264569	11.98 = Mean

The forecast population for the 6 sub-basins for the year 2000 becomes 264,569, restricted to 22,081 acres. This gives an overall population density of less than 12 persons per acre, which is still a comparatively low figure. In fact the density appears to be low enough to permit considerable diversity of density within individual neighborhoods even after allowance has been made for public open spaces and for commercial development.

The consequences of Proposal II are as follows. If it can be assumed that the provision of all sewer mains of 10 inches diameter and less is a private responsibility, which falls on the individual home owner, then the total cost of Proposal II is significantly less than for Proposal I. (This assumption is not unrealistic. In the Tualatin Basin master plan and elsewhere the public agency accepts the responsibility only for mains 12 inches in diameter and larger. No mains in Proposal I were less than 12 inches in diameter.) The total cost of Proposal II is estimated to be $11,622,920. This represents an average per capita cost of $32.79, or an average cost per household of $104.92. In terms of total cost Proposal II represents a saving of $2,912,595, or a cost reduction of 20%. (If Proposal II is expanded in scope to include mains of 10 inches in diameter, total cost increases to become $12,455,234. But this still represents a saving over Proposal I of $2,080,281, or a cost reduction of 14%.) If the total cost of proposal II is amortized over 30 years with an interest rate of 7%, this represents an annual charge of $936,649.28. This represents a mean annual per capita charge of $2.64, or a mean annual charge per household of $8.46.

Along with the reduction in costs Proposal II results in a considerable reduction in the size of the urban area. The actual urban acreage of Proposal II, in year 2000, is estimated to be 36,571 acres. Even assuming that the entire population forecast for the year 2000 is urban and is contained within the 36,571 urban acres, then the overall urban population density is only 9.65 persons per acre. Again it should be emphasized that this is sufficiently low to allow considerable diversity of settlement density within individual neighborhood, even after allowance has been made for supporting land uses. Overall the population density of the study area in year 2000 is identical to Proposal I, but the urban population density is higher (9.65 compared with 3.00) and the non-urban population density is lower. In Proposal II the land area saved from urban encroachment is estimated to be 81,429 acres. Whether this would remain primarily in agricultural use, as in 1970, cannot be forecast. But it would not be built upon for suburban residential use, and would retain potential for a variety of non-urban uses. Proposal II does not include sufficient main capacity for industrial development outside the urban residential area, and if sewage disposal is the limiting factor in developing the non-urban area, then it will remain in agricultural or extensive recreational use.

The incremental value which accrues to the land in the urban area in Proposal II is estimated as follows. Assuming, conservatively, that 40% of the total urban acreage is devoted to public open space and non-residential use, the 36,571 urban acres still represent an average lot size of 8,634 square feet. This is only slightly less than the average lot size found in the overall regression of the assessed value of an unbuilt residential lot in a platted sub-division in Chapter III. In the overall regression the mean lot size was 8,667 square feet. Thus the average increment in lot value from the provision of mean sewage transmission, estimated as \$680.00 in Proposal I, is applicable to Proposal II. This represents a value of \$2,392.36 per acre, which if invested for 30 years at 7% yields a total present value for the entire urban area of \$19,015,675.00 or \$53.68 per capita per annum or \$171.78 per household per annum. Proposals I and II are summarized in Table 4.2 and Figure 4.1.

Table 4.2. Comparison of major effects of Proposals I and II.

	Proposal I	Proposal II
(1) Total direct costs (\$)	14,535,515	11,622,920
(2) Annual charge, 30 years at 7% (\$)	1,248,077	936,649
(3) Annual charge per household (\$)	11.27	8.46
(4) Present value of incremental value p.a. (\$)	19,015,675	19,015,675
(5) - per household (\$)	171.78	171.78
(6) Annual net benefit (4) - (2) (\$)	17,767,598	18,079,026
(7) Urban area, acres	118,000	36,571
(8) Non-urban area, acres	0	81,429

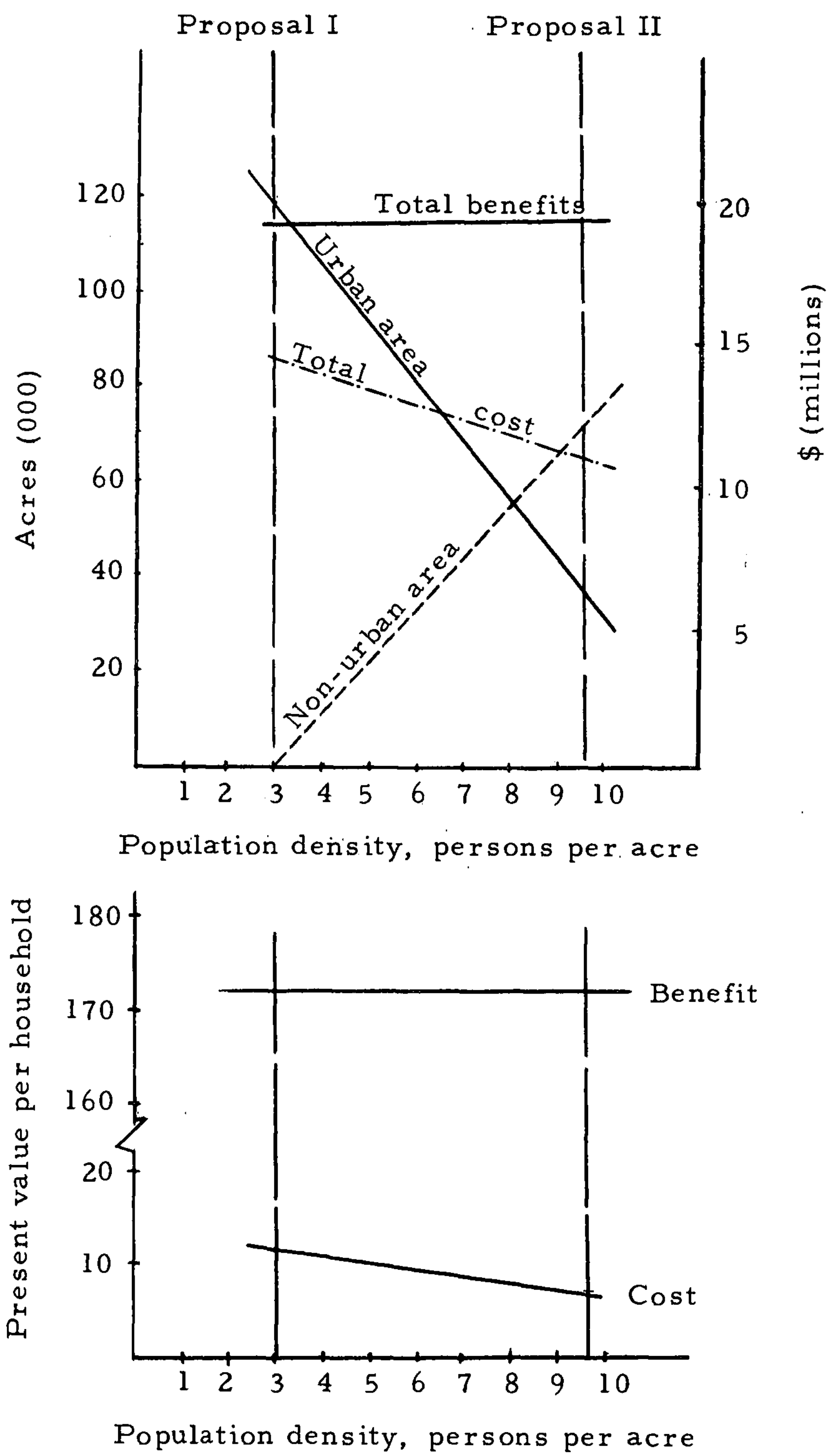


Figure 4.2. Comparison of major effects of Proposals I and II.

SUMMARY, CONCLUSIONS, AND IMPLICATIONS

Summary

This research began in an attempt to measure and evaluate the economic characteristics of open space. Open space is an amenity resource, one contributing to the quality of life, which has come to be regarded as a common property resource, equally available to all who wish to use it. As an amenity resource, open space poses problems of measurement and evaluation, and as a common property resource, the individual user will have no regard for maximizing the net revenue from open space, for the net revenue does not accrue to him. It is as a result of these two characteristics that major problems of open space management arise. Until progress is made in the measurement and evaluation of open space per se, the analyst must focus attention on the forces which directly or indirectly govern its allocation.

For this reason this research focused on one major force which governs the quantity and distribution of open space in and around the urban enviornment. Main sewer systems are priming actions with power to determine land use patterns and this power seems likely to increase as urban communities grow and seek to achieve a high quality living environment, and as the natural capacity of the environment to accept wastes harmlessly is used up. But despite its power to redistribute people, sewage transmission is a service which has received scant attention by analysts other than civil engineers. Their main preoccupation has been to ensure the provision of systems which meet their disciplinary criteria of physical efficiency. However, if it is an important function of theoretical social science to predict the unintended consequences of intentional human actions, and if it is necessary for society to control the systems within its reach to achieve its goals (page 4), then it is necessary to examine and understand more than just the physical characteristics of sewage transmission systems.

As populations increase in size and density, sewage transmission and treatment services have necessarily become collective goods, allocated by institutions other than the market. The market mechanism has been abandoned on pragmatic grounds, for these services exhibit, to some degree, all three commonly recognized forms of market failure, ownership, technical, and public goods externality (page 29). Individual sewage discharges into a common system are unmetered, sewage transmission and treatment are produced under conditions of decreasing cost, and sewer services produce some pure public goods outputs, such as improved public health, which are equally available to all members of society.

The study area chosen for this research exhibits all the characteristics of a rapidly suburbanising area (page 21). The population is increasing fast and at the same time the population density is declining, indicating that the urban land area is expanding more rapidly than the urban population. The urban fringe is extending disjointedly into formerly agricultural areas, and urban residential expansion has become a rural problem. Added to this, the land on the urban perimeter is geologically unsuitable for individual sewage disposal methods, even with very low population densities (page 19), and hydrologically the rivers and streams of the Tualatin basin are incapable of accepting additional organic wastes and degrading them harmlessly (page 90). Thus the problem in the study area results from the interaction of a set of economic, institutional, demographic, and geographic factors.

If a resource development project is proposed to solve the problem in the study area, given the objectives of the affected parties, two problems are posed in evaluating alternative means to achieving those objectives. What is the optimal combination of resources, and what is the optimal size of the project? Economic theory suggests that the least cost combination of resources for a given output exists whenever the ratio of the marginal physical products of the factors of production is equal to the ratio of the factor prices, and the optimum size of the project exists whenever the marginal benefit of increasing project size is equal to the marginal cost of the increase in size (page 38). Marginal analysis provides one criterion for choice among competing courses of action, and benefit-cost analysis is one specific tool designed to aid the decision maker when divergencies between private and social benefits and costs exist. But benefit-cost analysis is still beset by problems of evaluation and application (page 42). Public provision of a sewage transmission system raises questions of both economic efficiency and equity, of environmental and other amenity effects, of irreversibility and option demand. Such effects cannot be given explicit recognition in an analytic framework that necessitates market determined or simulated prices. For this reason, in a democratic society, a political decision procedure may be an acceptable mechanism for collective choice between alternatives when trade-offs must be made between efficiency and non-efficiency objectives, and when significant project effects go unpriced. Therefore it was proposed that a simple majority voting procedure among all individuals significantly affected by a project be adopted to supplement the array of information characterising the alternatives in order to determine the most preferred course of action (page 50). This proposal was made in accordance with the criteria for collective choice developed in the new political economy.

In this study an attempt was made to generate as much information as possible concerning the significant effects of a major sewage transmission system. Positive and negative, monetary and non-monetary effects were all considered. Two proposals representing extreme degrees of urban containment were investigated in detail in chapter IV, and less extreme intermediate proposals can be interpolated between them. The information generated could be presented to a vote of the individuals affected by a project to determine the most preferred position.

Conclusions

Sewage transmission services are a product of local governments. In Chapter I it was shown that for metropolitan areas in the United States, real per capita expenditures on sewer services have fallen steadily since 1957 (page 16). Over this period urban population densities have fallen continuously and it would have required greater expenditure per capita, or per urban acre, to sustain the quality of the sewer service. In the metropolitan areas of the state of Oregon real per capita expenditure for sewer services remained almost constant ($8.44 per capita in 1957 and $8.83 per capita in 1967) while population density fell drastically, from 246 to 128 persons per acre. Again, it would have been necessary for expenditure to have increased over time in order to maintain the quality of service. Other evidence of the declining quality of urban sewer services can be found in the declining water quality of rivers and streams passing through urban areas, the awareness of the public health hazard created by inadequate septic tanks, and the imposition of building bans until sewer systems were upgraded (page 24). The decline in quality of sewer services appears to be the result of very rapid population expansion (an increase of over 7% per annum in Washington County during the 1960's), an absence of collective action by incoming and existing residents, and an unwillingness to recognize that the capacity of waterways to accept and degrade organic wastes harmlessly is limited.

In Chapter III a production function for sewage transmission was estimated. A power function with system capacity a function of drainage basin area and population density gave the best fit. The parameter estimates, both highly significant, are the production elasticities of the independent variables, and show the percentage change in capacity relative to a percentage change in sub-basin area or population density. A percentage increase in area produces an almost equal one percent increase in system capacity, and a percentage increase in density produces almost a one-half of one percent increase in system capacity. The sum of the production elasticities shows the nature of the returns to scale, and in this case $\beta_1 + \beta_2 = 1.44$ showing increasing returns to scale. That is, if area and density are doubled, the necessary capacity to serve the enlarged system will be more than doubled. However it was shown that as system capacity increases the average per capita cost of the system declines continuously throughout the entire range of feasible systems (page 62). Thus as area and density increase although the physical capacity of the system increases, the average cost per capita or per household declines. If average cost per capita is continuously declining, marginal cost must be less than average cost, and marginal cost pricing must necessarily result in production at a loss. Sewage transmission is a natural monopoly, for a single producer can serve the entire market at the lowest per unit cost. This represents an extreme form of market failure. If it is required that, in order to achieve efficient allocation of income in consumption, consumers be charged a price equal to marginal cost, production under conditions of decreasing costs poses the question of how to raise the inframarginal residue. This question is not addressed here, although it is a similar problem of collective choice, of the form: "Which repayment policy, from an array of sub-optimal alternatives is to be preferred?"

The cost function for sewage transmission (page 62) shows that marginal cost per gallon of system capacity is continuously increasing, but this is misleading. The difference between the behaviour of marginal cost per gallon and marginal cost per capita is due to the declining influence of infiltration as a component of total system capacity as population density increases, and to the declining peak flow factor as the absolute size of the population increases. For example for a 500 acre sub-basin, the proportion of total capacity devoted to conveying ground water declines from 82% to 9% as population density increases from 1 to 100 persons per acre. At the same time as the population increases from 500 to 50,000 the ratio of peak to average dry weather flow falls from 3.5 to 1.5.

As distance of residence from the site of sewage treatment increases it was shown that the cost of sewage transmission increases (page 66). For a given distance, the cost per unit distance increases as population density falls. Consequently contiguous expansion of the urban fringe is less costly than discontiguous expansion, and high density discontiguous expansion is less costly than low density discontiguous expansion. For example, for a 500 acre sub-basin located 10 miles distant from the site of sewage treatment, the cost of sewage transmission decreases from $1,286.59 to $18.00 per household as population density increases from 1 to 100 persons per acre. Recent low density expansion of the suburban fringe in discontiguous tracts is therefore high cost expansion.

The provision of main sewerage to otherwise unimproved land results in considerable quasi-rents accruing to land. For typical residential lots in platted subdivisions the assessed value of the lot was estimated to increase on an average by $680.00 (page 77) when main sewer service is available. This increase in land value came at the expense of the provision of the sewer service, which was estimated to be in the range $274.30 to $5.38 as population density increased from 1 to 100 persons per acre, and as sub-basin area increased from 500 to 7,000 acres. Thus in all instances the marginal benefit accruing to land exceeded the marginal cost of the provision of that benefit. If a rational individual would be willing to pay at least as much as the increment to land value from the provision of the service, then a connection to a main sewer system could be sold for at least $680.00. At a price of $680.00 there would be a considerable net surplus accruing to the supplier of the service.

When the regression of assessed lot value against lot characteristics was stratified according to lot size (pages 74-75), it was shown that the addition to assessed lot value from the provision of main sewer service increased as lot size increased, with the exception of very large lots. Thus as lot size increased from an average of 3,523 square feet to 9,181 square feet, and population density fell from 23.74 to 9.11 persons per acre, the addition to lot value from the provision of main sewer service increased from $186.81 to $871.66 per lot. The estimates of the addition to lot value however could be criticised on at least two counts. First, because assessed lot value was used instead of market value, and second, because access to main sewer service was always accompanied by access to a main water supply in the study area. But given the data limitations, the estimates are considered to be reasonable approximations of the true value.

For the other significant parameter estimates in the overall regression of assessed lot value: β_2, assessed value increased with lot size by almost \$.08 per square foot; β_4, assessed value declined by \$71.51 per mile as radial distance from the central business district of the city of Portland increased; and β_5, assessed value increased by \$95.84 per mile as distance from a major urban highway increased.

Given the conditions for efficient allocation of resources and for a profit maximizing level of output in a perfectly competitive market

where $Q = f(X_1, X_2)$

and $$\frac{MP_{X_1}}{P_{X_1}} = \frac{MP_{X_2}}{P_{X_2}} = \frac{1}{MC_Q} = \frac{1}{P_Q}$$

where Q = system capacity

X_1 = sub-basin area

X_2 = population density

P_{X_1} = the price of X_1

MC_Q = the marginal cost of capacity Q

P_Q = the price of capacity Q.

it was shown that in a typical urban development (X_1 = 2,000 acres, X_2 = 10 persons per acre) the equalities above are not achieved. Instead

$$\left[\frac{5,810}{48.48} < \frac{559,870}{0.81} \right] > \frac{1}{0.32} > \frac{1}{680.00}$$

The resulting inequalities suggest that to allocate area and population density efficiently, population densities should increase, and to maximize profits area and population density should both decrease. However as capacity declines to the marginal cost of capacity increases, and so the inverse of marginal cost decreases, and the inequality is not removed. With price equal to marginal cost a profit maximing level of output can never be achieved when production is subject to decreasing costs.

In Chapter IV two hypothetical, basin-wide, sewage transmission systems for the study area were proposed and compared. Proposal I (page 88), represented general low density urban settlement of the entire study area, and Proposal II (page 97) represented accelerated development of the existing urban centers and containment of the suburban fringe. Although neither proposal generated population densities greater than that typical in existing western urban communities. Proposal II produced a considerable saving in both monetary terms ($2,912,595 or $26.62 per household), and in unbuilt land acreage (81,429 acres). The monetary saving may appear to be small but the reduction in the size of the built up area appears to be considerable. In Proposal II the urban fringe is contained, but the freedom of individuals to settle in the existing urban centers in typical suburban densities (less than 12 persons per acre) is not restricted. Both proposals accepted the master plan population forecast for the study area, but the settlement density was considered to be a variable. The population distribution was assumed to be controlled by the coordinated provision of urban priming actions, and a sewage transmission system is an example of these. In this way a priming action restricts the freedom of the individual, but the collective goals of the community can be satisfied. A voting procedure on which alternative course of action is preferred may suggest whether the collective gain acquired exceeds the individual losses sustained.

In this example of a rapidly urbanising area the provision of an urban public service, as in Proposal II, was, was accompanied by an increase in direct net dollar benefits with a quantitative increase in an amenity resource, unbuilt land in agricultural, woodland, or recreational use (page 100). This was made possible by recognizing that communities possess multiple goals (low-density suburban living, improved water quality, and the availability of open space), that resource development projects rarely have single effects (sewage transmission, improved public health, and suburban containment), by identifying the production and cost characteristics of the service produced, and by defining functional spatial units (drainage sub-basins and not census tracts) as the basic planning units.

Implications

There is an additional result of this study which, while it is not a direct conclusion of the research on sewage transmission per se, may be of value in relation to the process of collective decision making. This is a set of conjectures about the role, and conduct of the institutions charged with identifying and satisfying the demand and supply of public goods. These conjectures arise as the result of trying to understand what is the public interest, how is collective choice made, and how well does the solution proposed in this thesis (the use of marginal analysis supplemented by a political voting procedure) resolve the collective choice question raised by the need to expand a sewage transmission system.

But first it will be necessary to understand how the Unified Sewerage Agency (U.S.A.) was created and what its responsibilities are. Briefly, the U. S. A. and the Tualatin Basin Master Plan were a response to a crisis. Water quality in the Tualatin River and its tributaries had fallen progressively to an unacceptably low level, and there was every indication that this decline was likely to continue as population growth proceeded at an accelerating rate. From the outset the objective of the U. S. A. was to assume responsibility for one major function, basin-wide water quality. A water and sewerage master plan, financed in part by federal funds, was prepared by consulting engineers. The master plan proposed a physically efficient sewerage system for the basin, and also recommended the creation of a central agency with power to propose and finance the investment needed to improve water quality. It was also proposed that the county board of commissioners become the directors of the agency, and that they appoint a nine-man commission to advise on technical and administrative questions. The proposals of the master plan were put to the electorate in the study area along with a request for 36 million dollars in general obligation bonds in April, 1970. The proposal was accepted by a 2-to-1 vote of less than a majority of the eligible voters. The agency therefore, was created with only one principle function, "to serve the district adequately" (Potter, 1971, p. 1858), and this was operationally defined as meeting the water quality standards of the State Department of Environmental Quality. The electorate was faced with an all-or-nothing decision (to accept the master plan proposals and its implications or not) which was not accompanied by economic analysis of alternatives.

The outline of the origins of the U. S. A. indicates that investment in sewerage has failed to keep abreast of population growth. This conclusion might indicate that new investment should be made to restore basin water quality either to its original level, or to the minimum standard set by the State Department of Environmental Quality. Economic analysis, however, would suggest that new investment should proceed until the marginal benefit achieved by the last unit of investment is equal to the marginal cost of that investment. This would be the optimum level of investment. But it is a contention of this research that such a rule for efficiency is not an operational rule. The sewerage plan should be consistent with all the objectives of the land use plan which seeks to achieve the goals of the society. Such social goals include more than economic efficiency, and the achievement of these goals requires more than the efficient production of water quality. Society possesses multiple goals, and major resource development projects rarely have single effects. It is in order to satisfy these goals and evaluate the non-marketed effects of a public project that the proposal was made to supplement the net benefits argument with a political voting procedure. That this additional criterion is necessary is the result of the operational failure of the net benefits criterion. That this additonal criterion may be a useful way of overcoming this failure is the result of two observations on methodology in social science. These are, first, that problem analysis and decision making institutions are not entirely seaprate, and second, that individual preferences and the public interest are similarly interdependent.

Analytical and Institutional Inseparability

As was indicated in Chapter II, a theory is built in three parts, conjectural predictions, an institutional-organizing structure, and a set of inferential predictions. The conjectural predictions and the institutional-organizing structure are the assumptions of the theory. The assumptions of a theory are never entirely realistic, but it is reasonable to ask whether they are "sufficiently good for the purpose in hand" (Friedman, 1953, p. 15).

Some recent proposals and criticisms of public water resource planning and evaluation provide some clear statements of the complementarity of analytics and institutions (Bromley, Schmid and Lord, 1971). Assume that the role of the technical side of planning is to provide information to the political decision making process. But the technician operates within the constraints imposed upon him by the political institution. Therefore in order to evaluate the technical information generated, it is first necessary to understand the institutional structure. Bromley et al (1971) indicate the existence of institutional inadequacies in the water resource planning process. These inadequacies are also present in local urban systems planning. For example, with very few exceptions such as national defense, the demand for government projects is local in origin, although projects may be supplied by governments at all levels.

Such projects produce social, economic, and environmental consequences which are also predominantly local. Non-local effects tend to be less intense than local effects, although in the aggregate non-local effects may be considerable. As Irving Fox has indicated project costs and benefits are frequently diffused, but typically benefits are concentrated while costs are distributed more evenly (Fox, 1965). However, despite this appreciation of government processes catering to local ends, local participation is often limited, and decision processes are weighed in favour of the developmental agencies. The decision making process does not offer real choice at the local level, and in this way it violates criteria of democratic decision making. There is a local information requirement (the potential positive and negative project effects at the local level), and there is also a local institutional requirement. For to meet the necessary conditions for democratic choice, there is a need for participation by all individuals who are likely to be significantly affected by a decision.

Wantrup has differentiated three levels in a decision-making hierarchy. At the lower level there are the public and private "firms" which control inputs and outputs. At the second level is the institutional framework which controls the operations on the lowest level. At the third levels are the highest level institutions, which Wantrup calls the policy level (Wantrup, 1967). Thus the institutions of the second level are constraints on the actions on the first level. Davis and Whinston (1965) have shown that social welfare will be at best increased, or at least unchanged, if the number of institutional constraints on action is reduced. In this way first and second level decision making become inseparable. Effective analysis of resource allocation in the provision of urban public services must therefore focus upon the first level analytics and the second level institutions.

With respect to the Unified Sewerage Agency of Washington County, the institutional structure created effectively denies individuals at the local level participation in the decision-making process, and at the same time imposes no restrictions on the actions of the agency, other than to provide an adequate level of service, which is interpreted to mean the provision of physically efficient systems to meet minimum water quality standards.

Individual Preferences and the Public Interest

The assumption that individual preferences are to count in decision making is an ethical one. Analysis of collective behaviour could be based upon an aggregate conception of society. The political reform tradition is based upon the "public" as a separate entity, rather than upon the individual as the fundamental unit of society. But as Ernest Nagel has shown, the ultimate constituents of the social world are individuals, and operationally, statements about social events can be logically deduced from psychological statements about human individuals (Nagel, 1961, p. 540). Economic theory has focused on the individual, with collective behaviour being the sum of individual actions, and not that of a separate body. For these reasons, the postulate of individualism is chosen as the basis of the analysis of collective choice. This however implies that individual perferences must be articulated, which in turn implies that institutions which constrain individual participation must be relaxed or removed. For collective action is required to satisfy individual demands when the private goods market fails. If individual preferences are to count, and if any publicly induced collective good is a public good (Steiner, 1969, p. 9), then individual preferences and the public interest are inseparable. Again, the institutional implication is that a means must be found for individual participation in collective choice. The primacy of the individual does not deny the existence of a public interest, but it does imply that the performance of the public sector is to be judged in terms of how well it satisfies individual demands.

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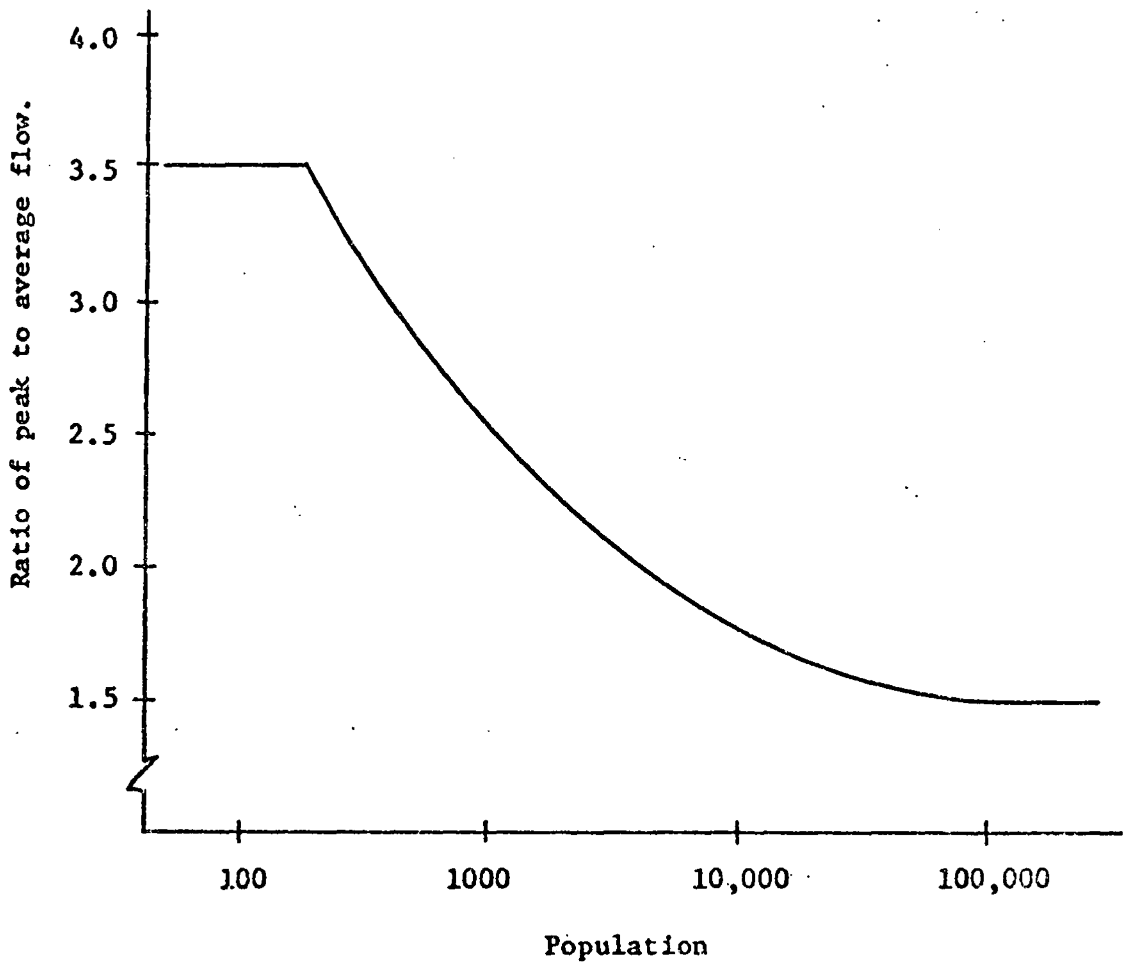
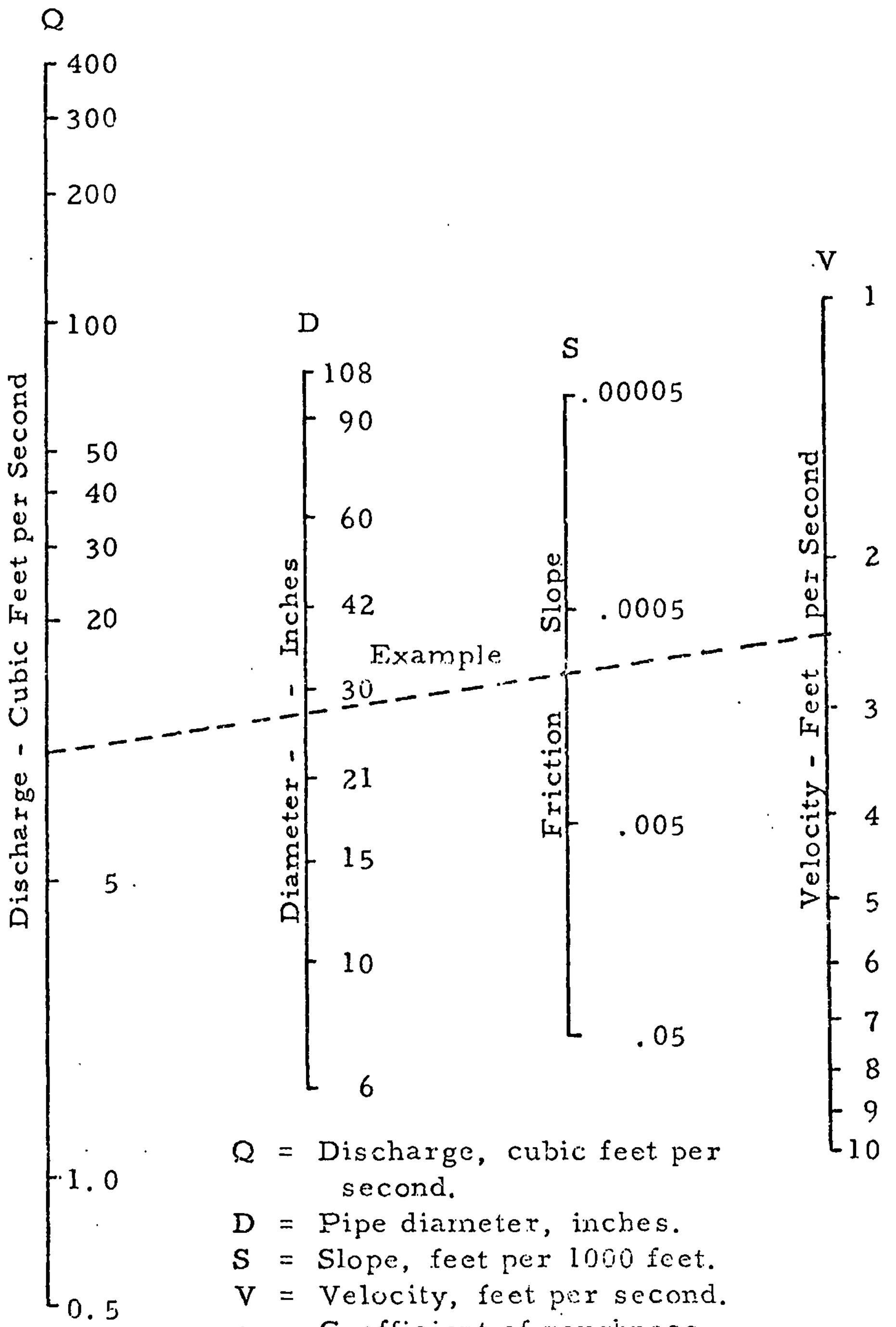
APPENDIX

Appendix Figure 1 Ratio of peak flow to average dry weather flow in sanitary sewers.

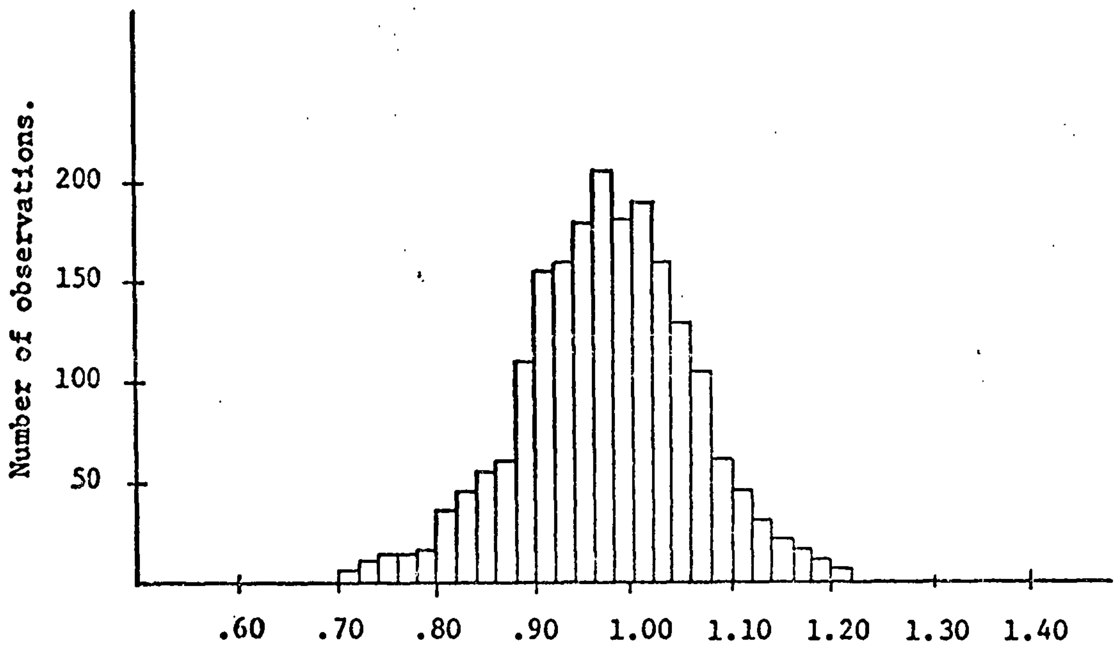




Q = Discharge, cubic feet per second.
D = Pipe diameter, inches.
S = Slope, feet per 1000 feet.
V = Velocity, feet per second.
n = Coefficient of roughness.

Appendix Figure 2. Alignment chart showing flow of water in concrete pipe lines, assuming pipe lines are in full flow, and with Manning's n = .013.

Appendix Figure 3. Frequency distribution of sales ratio for Washington County, 1971.



Sales ratio, assessed value / market value.

Source, Richard Brenner, Sales Data Analyst, Washington County, Oregon. Personal communication.

Appendix Figure 4. Diagramatic represetation of drainage sub-basin interrelationships.

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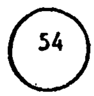

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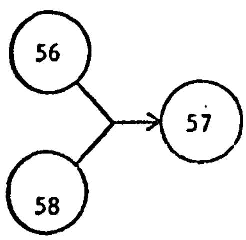

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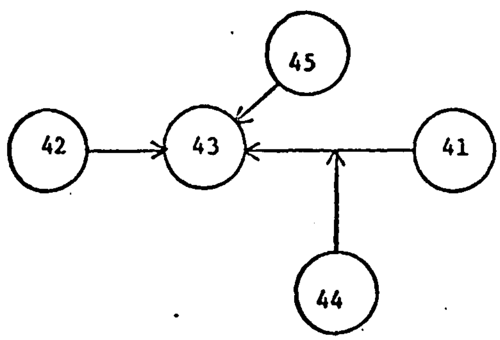

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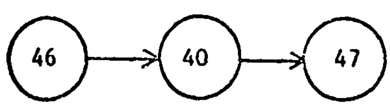

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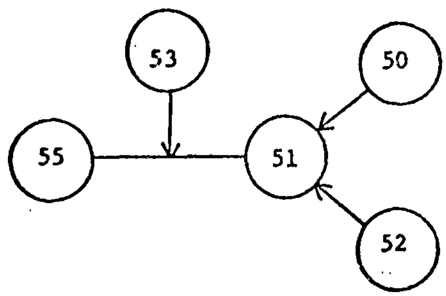
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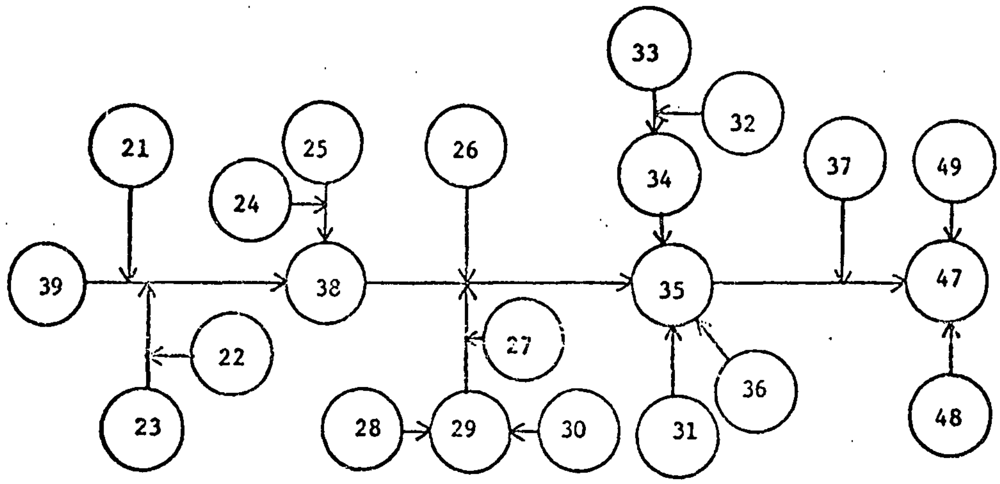
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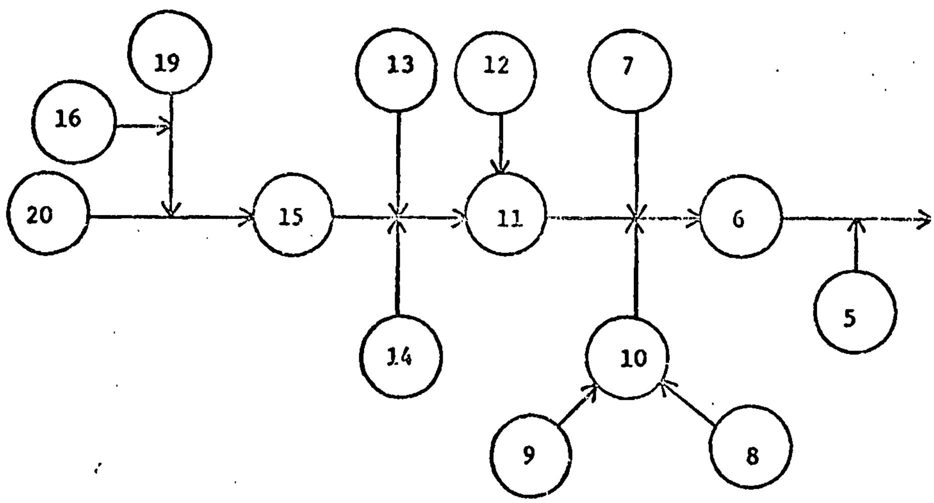
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Appendix Table 1. The output of sanitary sewage as a function of drainage basin area and population density, in gallons (x 1000).

Basin area, acres		Population density - persons per acre							
		1	5	10	15	20	25	50	100
500	1[a/]	175	525	990	1425	1800	2112	4075	7750
	2[b/]	800	800	800	800	800	800	800	800
	3[c/]	975	1325	1790	2225	2600	2912	4875	8550
1000	1	250	990	1800	2595	3360	4075	7750	15000
	2	1600	1600	1600	1600	1600	1600	1600	1600
	3	1850	2590	3400	4195	4960	5675	9350	16600
1500	1	345	1425	2595	3847	5010	6075	11400	22500
	2	2400	2400	2400	2400	2400	2400	2400	2400
	3	2745	3825	4995	6247	7410	8475	13800	24900
2000	1	450	1800	3360	5010	6280	7750	1500	30000
	2	3200	3200	3200	3200	3200	3200	3200	3200
	3	3650	5000	6560	8210	9480	10950	18200	33200
2500	1	525	2112	4075	6075	7750	9562	18750	37500
	2	4000	4000	4000	4000	4000	4000	4000	4000
	3	4525	6112	8075	10075	11750	13562	22750	41500
3000	1	630	2595	5010	7020	9240	11400	22500	45000
	2	4800	4800	4800	4800	4800	4800	4800	4800
	3	5430	7395	9810	11820	13940	16200	27300	49800
3500	1	717	3010	5600	8085	10570	13125	26250	52500
	2	5600	5600	5600	5600	5600	5600	5600	5600
	3	6317	8610	11200	13685	16170	18725	31850	58100

Appendix Table 1. Continued.

Basin area, acres		Population density - persons per acre							
		1	5	10	15	20	25	50	100
4000	1[a/]	800	3360	6280	9240	12160	15000	30000	60000
	2[b/]	6400	6400	6400	6400	6400	6400	6400	6400
	3[c/]	7220	9760	12680	15640	18560	21400	36400	66400
4500	1	900	3690	7020	10327	13590	16875	33750	67500
	2	7200	7200	7200	7200	7200	7200	7200	7200
	3	8100	10890	14220	17527	20790	24075	40950	74700
5000	1	990	4075	7750	11400	15000	18750	37500	75000
	2	8000	8000	8000	8000	8000	8000	8000	8000
	3	8990	12075	15750	19400	23000	26750	45500	83000
5500	1	1072	4455	8470	12540	16500	20625	41250	82500
	2	8800	8800	8800	8800	8800	8800	8800	8800
	3	9872	13255	17270	21340	25300	29425	50050	91300
6000	1	1140	5010	9240	13590	18000	22500	45000	90000
	2	9600	9600	9600	9600	9600	9600	9600	9600
	3	10540	14610	18840	23190	27600	32100	54600	99600
6500	1	1235	5232	9945	14625	19500	24375	48750	97500
	2	10400	10400	10400	10400	10400	10400	10400	10400
	3	11635	15632	20345	25025	29900	34775	59150	107900
7000	1	1323	5600	10570	15750	21000	26250	52500	105000
	2	11200	11200	11200	11200	11200	11200	11200	11200
	3	12523	16800	21770	26950	32200	37450	63700	116200

a/ Peak flow. b/ Infiltration. c/ Total.

Appendix Table 2. Total cost of main sewer construction per linear foot. Assuming the installation of Class III concrete pipe at an average depth of 10 feet, including the cost of surveying, trenching, excavation, backfill, pipe and manholes every 500 feet.

Pipe diameter	Total cost per linear foot
12	9.19
15	11.17
18	16.16
21	17.70
24	20.33
27	20.44
30	22.37
33	23.95
36	25.53
42	40.81
48	46.75
54	47.57
60	54.39
66	60.62
72	71.65
78	76.15
84	82.15
90	92.56
96	97.06

Appendix Table 3. Total cost of sewage transmission as a function of drainage basin area, and population density, in dollars (x 1000).

Basin area, Acres	Population density - persons per acre							
	1	5	10	15	20	25	50	100
500	42.9	52.1	52.1	52.1	52.1	52.1	75.4	95.4
1000	60.7	73.7	106.7	106.7	116.8	116.8	134.9	168.5
1500	90.3	130.6	143.1	164.3	164.3	165.2	193.6	377.9
2000	150.8	165.2	189.8	190.8	190.8	208.8	380.9	436.4
2500	168.6	212.1	213.3	233.4	233.4	249.9	425.9	567.6
3000	202.3	232.4	233.7	255.7	273.4	291.9	534.4	693.0
3500	251.0	252.4	276.2	297.7	315.2	503.9	577.2	748.5
4000	268.4	269.8	316.1	340.0	538.7	538.7	627.9	947.8
4500	282.2	313.2	335.3	357.4	571.4	654.5	761.5	1066.2
5000	301.7	353.5	376.8	593.0	593.0	689.9	802.7	1212.4
5500	316.4	370.7	395.2	621.9	723.6	723.6	938.9	1271.5
6000	361.7	387.2	649.6	649.6	755.8	769.1	980.0	1496.4
6500	376.4	429.6	676.1	786.7	786.7	800.5	1020.1	1633.2
7000	418.6	445.8	701.6	816.3	830.7	830.7	1251.1	1694.9

Appendix Table 4. Average total cost of sewage transmission per household, as a function of drainage basin area and population density, in dollars (1 household = 3.2 persons).

Basin area, acres	Population desnity - persons per acre							
	1	5	10	15	20	25	50	100
500	274.50	66.72	33.38	22.24	16.67	13.34	9.63	6.11
1000	194.11	47.20	34.14	22.75	18.69	14.94	8.64	5.38
1500	192.64	55.74	30.53	23.36	17.54	14.11	8.26	8.06
2000	241.34	54.21	30.37	20.35	15.26	13.38	12.19	6.98
2500	215.84	54.30	27.30	19.90	14.94	12.80	10.91	7.26
3000	215.84	49.57	24.93	18.18	14.59	12.45	11.39	7.39
3500	229.50	46.14	25.25	18.02	14.43	18.43	10.56	6.85
4000	214.69	43.17	25.28	18.14	21.54	17.25	10.05	7.58
4500	203.52	44.54	25.12	16.96	20.32	18.62	10.82	7.58
5000	193.06	45.25	24.13	25.31	18.98	17.66	10.27	7.74
5500	184.06	43.10	22.98	24.13	21.06	16.83	10.91	7.39
6000	192.90	39.01	34.66	23.10	20.16	16.42	10.46	7.97
6500	185.31	42.27	33.28	38.72	19.36	15.78	10.05	8.03
7000	191.33	40.77	32.06	32.06	18.98	15.20	11.42	7.74

Appendix Table 5. The relationship between pipe diameter, slope, and depth of burial.

Pipe diameter inches	Pipe capacity m. g. d.	Slope, feet per 1000 feet	Linear distance to fall 20 ft. in miles
12	1.26	3.00	1.26
15	1.94	2.25	1.68
18	2.87	1.80	2.10
21	3.81	1.50	2.53
24	4.97	1.30	2.91
27	6.26	1.10	3.44
30	7.10	0190	4.21
33	9.48	0.80	4.73
36	11.29	0.70	5.41
42	15.42	0.55	6.89
48	19.67	0.48	7.89
54	25.16	0.40	9.47
60	31.61	0.35	10.82
66	37.41	0.31	12.22
72	46.44	0.28	13.53
78	54.18	0.25	15.15
84	61.28	0.23	16.47
90	70.95	0.21	18.04
96	78.05	0.20	18.94

Table 6. Capital cost of sewage pumping stations, as pipe diameter increases.

Pipe diameter inches	Capital cost $(000)	Cost per gallon per foot, $	Cost per household per 10 miles
12	40	.00000476	1012.09
15	40	.00000231	60.82
18	40	.00000125	32.44
21	64	.00000124	24.33
24	64	.00000083	23.43
27	64	.00000056	11.89
30	64	.00000040	11.89
33	88	.00000037	6.94
36	88	.00000027	6.32
42	136	.00000024	5.20
48	160	.00000019	4.32
54	208	.00000016	3.51
60	232	.00000012	2.29
66	280	.00000011	2.10
72	328	.00000009	1.94
78	376	.00000008	1.76
84	424	.00000007	1.65
90	496	.00000007	1.47
96	544	.00000007	1.31

Appendix Table 7. Mean values of variables used in estimating the value of sewage transmission.

	Mean Y	Mean X_1	Mean X_2	Mean X_4	Mean X_5
Overall	2993	22.27	8667	9.04	0.87
Group A	2002	21.00	3523	7.41	0.66
Group B	3157	27.86	7144	8.97	0.78
Group C	3278	19.56	9181	9.37	1.00
Group D	3304	11.90	19810	10.68	1.14

Appendix Table 8. Area and population of Tualatin River sub-basins for 1970, and 2000, proposals I and II.

Sub basin number	Area acres	Population 1970	Population 2000 Proposal I	Population 2000 Proposal II
5	1267	515	1281	515
6	1190	495	1231	495
7	2669	1166	2900	1166
8	2918	1173	2917	1173
9	2502	707	1758	707
10	5286	5657	14070	5657
11	3290	4966	12351	36415
12	2074	3488	8675	3488
13	2867	7425	18467	7425
14	3853	3140	7810	3140
15	2010	5932	14754	5932
16	768	1274	3169	1274
19	3302	6539	16263	6539
20	4845	21675	53909	67988
21	1398	6252	15550	6252
22	2662	8890	22110	34336
23	3110	5822	14480	5822
24	1734	2050	5098	2050
25	1760	1443	3589	1443
26	3398	1852	4606	1852
27	2016	1603	3987	1603
28	3130	414	1030	414
29	531	446	1109	446
30	2298	991	2465	991
31	2432	1799	4474	1799

Appendix Table 8. Continued.

Sub basin number	Area acres	Population 1970	Population 2000 Proposal I	Population 2000 Proposal II
32	2323	835	2077	835
33	1222	869	2161	869
34	2598	2849	7086	2849
35	3878	4021	10000	4021
36	582	741	1843	741
37	1210	1827	4656	1827
38	1792	2085	5186	2085
39	2656	1978	4920	1978
40	3302	3008	7481	3008
41	3034	811	2017	811
42	1568	993	2470	993
43	2976	476	1184	476
44	1293	207	515	207
45	954	153	381	153
46	2175	702	1746	702
47	1645	263	654	263
48	1562	2570	6392	2570
49	2477	3370	8382	27048
50	2323	2051	5101	2051
51	1850	2254	5606	19938
52	1082	668	1661	668
53	589	370	920	370
54	1414	889	2235	889
55	1555	1034	2572	1034
56	1478	2153	5355	2153
57	6957	9011	22412	75513
58	384	77	192	77