12-1-1973

Systematic Development Of Methodologies In Planning Urban Water Resources For Medium Size Communities, Economic And Environmental Impacts Of Surface Runoff Disposal Systems

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TECHNICAL REPORT NO. 39

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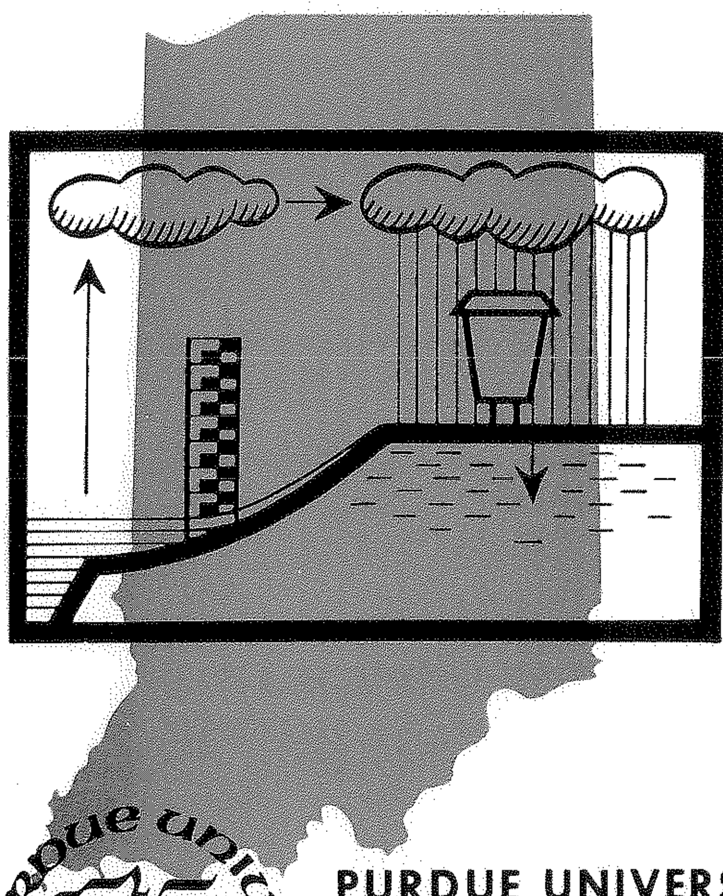
Economic and Environmental Impacts of Surface Runoff Disposal Systems



by

William L. Miller

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December 1973

PURDUE UNIVERSITY
WATER RESOURCES RESEARCH CENTER
WEST LAFAYETTE, INDIANA

ECONOMIC AND ENVIRONMENTAL IMPACTS OF SURFACE RUNOFF DISPOSAL SYSTEMS

by

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This is a partial completion report contributing to the project entitled "Systematic Development of Methodologies in Planning Urban Water Resources for Medium Size Communities".

The work upon which this report is based was supported in part by funds provided by the United States Department of Interior, Office of Water Resource Research as authorized by the Water Resources Act of 1964 (P.L. 88-379) and is part of the Title II Project C-3277 entitled "Systematic Development of Methodologies in Planning Urban Water Resources for Medium Size Communities" Grant No. 14-31-0001-3713.

Purdue University Water Resources Research Center

Technical Report Number

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Foreword

This report is based upon research conducted by Mr. Steven Erickson and reported in his Master of Science thesis. The research involves the comparison of alternative system designs to dispose of runoff from rainfall in urban and suburban areas. The systems were compared on the basis of system cost and water quality parameters. This type of comparison provides communities with information about the relationship between cost and water quality. With that information a community can choose that system design which provides the combination of cost and water quality which it selects as most appropriate to its needs.

The model developed to compare alternative systems for storm water removal was applied to a watershed in West Lafayette, Indiana. Based on analysis of this watershed implications were drawn about the drainage system cost and water quality associated with alternative land use in Tippecanoe County, Indiana in the year 2020.

The authors are indebted to the members of the interdisciplinary research committee for their help in obtaining data for the analysis and suggesting additional system designs that should be considered in the analysis. Dr. Delleur and Dr. Bell were particularly helpful with the hydrology and water quality aspects of the research, respectively. In addition, we appreciate the financial assistance of the Office of Water Resources Research, Dept. of Interior, Washington, D.C. and the Department of Agricultural Economics, School of Agriculture, Purdue University, West Lafayette, Indiana.

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CHAPTER I

INTRODUCTION

The Water Resource Planning Problem

The public is presently concerned about water quality and it is apparent that this issue will be of concern in the future. This concern is intimately related to acknowledged increases in the quantity demanded of aesthetic enhancement, recreational facilities, and waterfronts for public uses. [39, p.2] Due to the realization that multiple objectives should be considered in any project formulation, the Water Resources Council introduced new procedures for project evaluation. These procedures require analysis of both the economic and the environmental impact of investments in water and related land resource development.

Work on multiple objective planning models relevant to the water quality area has recently been published by Miller and Byers. [41] The objectives of this research were to develop a multiple objective planning model, apply the model to a water development project, and demonstrate how to display multiple objective project designs. The two social objectives of national economic development and water quality were selected for analysis. Display of results was in the form of trade-off functions which depicted how enhancement of water quality would require a sacrifice of net national benefits in small watershed projects.

There has been little research relating the multiple objective planning framework to the problem of storm water drainage system design in urban and semi-urban areas. Although considerable attention has been given to the water quality problem related to sanitary sewer disposal of household wastes, similar attention has not been given to rainfall runoff which also carries waste products and pollutants. [39, p. 4] Rainfall runoff is not only a problem in urban areas, but it must be considered to be a major source of stream water pollution in areas of low population density. Storm water drainage system design should incorporate the same objectives of enhancing environmental quality and improving the level of economic efficiency that are being applied to other public water resources investments.

Some research related to the storm water quality problem has been completed recently, although it does not approach the problem using the multiple objective planning framework. Research on the effects of urbanization on stormwater runoff quality has been completed by Angino, et al. [1, p. 135] The authors suggest that in some areas use of stormwater may be economically justified in the near future. However, they assert that large amounts of contaminants from many sources are being added to storm water. The increased pollution loading increases the social cost of environmental quality control since, in some areas, storm water runoff actually requires treatment.

The effects of urbanization on system costs has been studied by Hammer. [20, p. 1530] Stream channel enlargement occurs in response to the change in streamflow which accompanies urbanization. The most critical factor in determination of the amount of channel improvement from a given level of urbanization appeared to be the basin slope.

The overall urban water system design problem is discussed thoroughly by Costello. [68, p.116] He indicates that it may be desirable to include the impact of designs not only upon the monetary cost of the system, but also upon the environmental quality, social well-being and regional and national impact. He stresses the need for more research which evaluates these impacts.

The Tippecanoe County Drainage System

An excellent location to improve the methodology for drainage system design is Tippecanoe County, Indiana. It is a county with a population of about 109,000. The sole metropolitan area in this county is that of Lafayette-West Lafayette. This urban area exhibits several methods of rainfall runoff disposal, such as, pipeline transmission systems in the cities and open ditches on the rural-urban fringe of the Lafayette area. The county is expected to continue to urbanize with a population by 2020 double its present size. As rural areas develop into urban residential or urban commerical areas, presently operating rainfall runoff removal systems will be modified and new ones will be installed. The problem for Tippecanoe County, is to select among alternative designs for rainfall runoff removal systems. Each system design will have differing impacts upon the water quality in the community and will have different economic costs of installation and operation.

A recent study by Stanley Consultants indicates that extensive development of sanitary sewer, stormwater sewers and water supply systems will be required to meet the needs of the growing Tippecanoe County population. [69, pp. XI-3 - XI-8]. They indicated that there is a "need for more detailed design studies as to specific locations, sizes, and types of facilities generally recommended." [69, p. II-2] Although their research provides substantial information about the general cost for specific systems, they did not attempt in the prefeasability study to compare alternative system designs or to examine the impact on environmental quality of those systems which were presented in the report. In addition due to the source of financial resources for the study, they concentrated primarily on the small towns in the county.

Research Objectives

This study will examine initially alternative designs for a watershed in Tippecanoe County, Indiana. The initial part of the study will be expanded to examine the impact of continued urbanization in the Tippecanoe County area to the year 2020. Presentation of the economic and water quality impact of alternative system designs will aid citizens and planners in selection of the plan they desire. In addition, it will illustrate a methodological framework they can use to compare other designs not considered in this study.

The economic impact of the project design will be closely tied, through model constraints, to the water quality effects of project implementation. This procedure will allow illustration of tradeoffs between system costs and level of water quality. The assumption made for this study is that the public is concerned not only with the costs of a given drainage system, but also with the impacts that system has upon the water quality of the area. The following specific objectives will be examined in detail in this research.

1. To illustrate a design comparison model which will aid city planners and engineers in choosing among differing rainfall runoff transport systems.

CHAPTER II

THEORETICAL CONSIDERATIONS AND THE PROGRAMMING FRAMEWORK

The purpose of this chapter is to develop theoretical considerations relevant to the problems under study. This chapter has two major parts, i.e., theoretical implications relevant to this study, and an outline of the programming framework.

System costs are particularly relevant to this case study since they measure the dollar sacrifice society must make to derive an improved level of water quality. This study will not attempt to establish a specific value on the "output" of a selected system. It will be assumed that society maximizes a social "well-being" (welfare) function and hence will choose some combination of system cost and some level of water quality.

It is further assumed that society attempts to achieve a maximum amount of satisfaction from a given level of income. From this assumption, it follows that consumers will allocate their expenditures to the point where the last dollar spent for any specific item will yield the same amount of satisfaction for all items. Kneese [29] outlined a similar assumption and further stated:

> "When this condition exists, it follows that the market price of a particular commodity reflects its worth, or goodness, or want-satisfying power."

Therefore, system costs were utilized in this study to illustrate the choice society makes in selection of a specific runoff disposal system. Related to system costs will be water quality. Both cost and water quality were used to develop a trade-off between the two social objectives of economic efficiency and environmental quality.

The Production Function and System Design

Several production functions were examined to provide analysis of a wide range of system designs. The production function relates amounts of the variable input(s) to the total output of a product. There are four types of possible responses of total product to the addition of the variable factors of production [32, pp. 119-130]. First, the production function may exhibit increasing total product. This simply means that each extra unit of a variable resource adds more to total output than the previous unit. Secondly, a point may be reached where each incremental unit of input results in the same addition to total product as the previous unit. This exemplifies constant total product. The third response of total product occurs when additional units of the input increase total product by less than the last unit of the input added. Finally, decreasing total product may occur when the additions to total product of an added unit of the variable resources are negative.

Each of these types of response is combined into one graphical presentation of the theoretical production function outlined in Figure 2.1. This function illustrates the improvement in water quality that could result as the factors of labor and capital are increased in fixed proportions while other factors are held constant.

2. To develop trade-off relationships between economic costs and water quality for alternative stormwater systems.

3. To examine the impact of alternative urban development in Tippecanoe County on the cost and water quality of stormwater removal systems.

The research is presented in several chapters which will include the following topics. Chapter II will provide an overview of the theoretical considerations involved in this case study. The concept of developing a trade-off relationship to depict numerically the change in water quality due to a specific increase in spending will be reviewed in this chapter. It will provide a review of the theory and usefulness of interger programming as a decision making tool and specification of the empirical model used in this study. Chapter III will be devoted to an in-depth discussion of the methodology and data base used to develop alternative designs. Since this is a case study problem, a detailed outline of the watershed area will be provided to aid city planners and engineers in employing a similar type methodology for watersheds in their particular area. Chapter IV will present the empirical analysis and will discuss these results. Chapter V, the final chapter, will state the conclusions of this research, indicate the limitations of the study, and provide suggestions for future research.

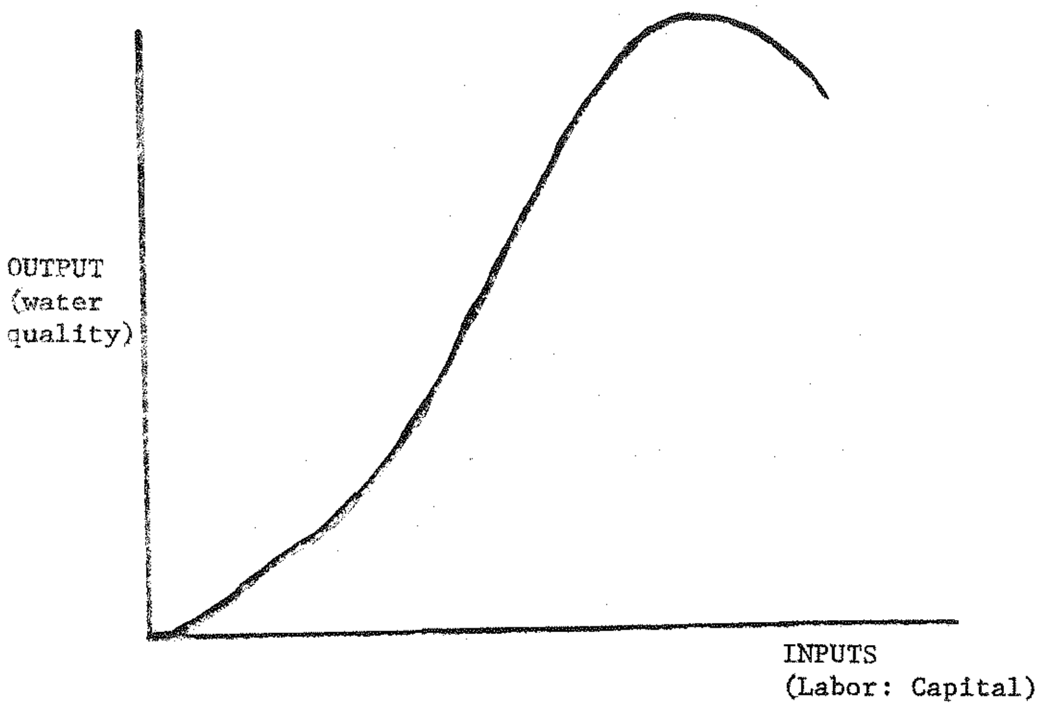

Figure 2.1 The Theoretical Production Function.

The Relationship Between the Production Function and Cost

In the short run, economists categorize resources as fixed and variable. This enables one to classify costs as fixed and variable. Total variable costs are those costs which fluctuate directly with the level of production. However, total fixed costs differ from variable costs in that they are constant regardless of the level of production.

Since variable costs can be linked directly with the level of output, the total variable cost curve and the production function are directly related. When a constant price is paid for each additional unit of the variable inputs that are employed, the total variable cost curve is a mirror image of the production function as shown in Figure 2.2 [32, p. 97].

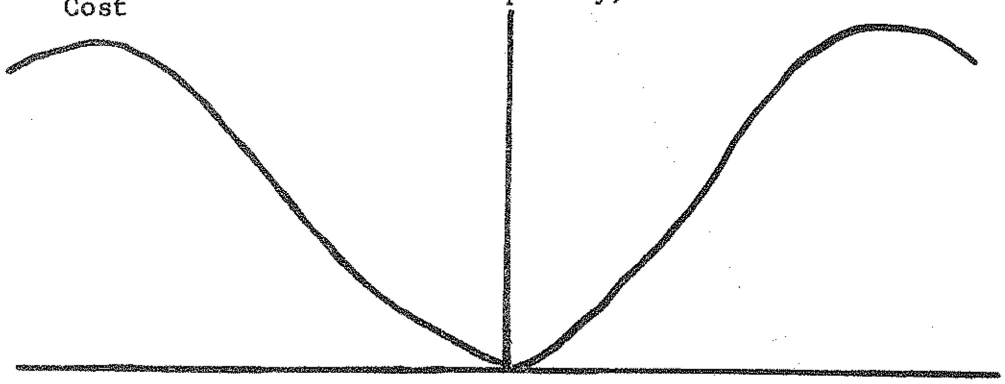

Figure 2.2. Relation of Costs to the Production Function

The Trade-Off Relationship

The trade-off relationship which is helpful in comparing alternative systems designs to achieve improved water quality involves comparison of the total cost functions for several systems. In this research several production functions were developed to represent alternative system designs. Each function was associated with a particular combination of labor and capital in fixed proportions. As the unit combination of labor and capital were increased while other factors were held constant, total product and associated total variable cost functions were developed as illustrated in Figure 2.2. Another total variable cost function was then developed for a different system design, i.e., a different ratio of labor to capital variable factors of production. Then the fixed cost of production was added to the total variable cost functions to develop a total variable cost function for each system design. Since linear production functions were assumed for each system design, the total cost functions for alternative systems can be illustrated as presented in Figure 2.3.

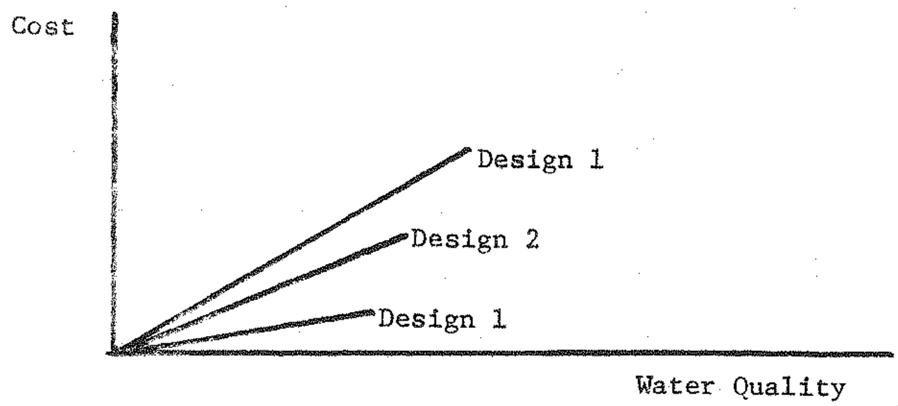

Figure 2.3. Total Cost Functions for Alternative System Design

In comparing these system designs it is apparent that system design 3 is preferrable to either design 2 or 1 because it is possible to achieve a given level of water quality for a lower cost with design three than with either of the other two designs. However, design 3 can only achieve an initial improvement in water quality. To achieve higher levels of water quality it is necessary to shift to more costly technology. Therefore the relevant trade-off involves discovering through empirical measurement which alternative system designs will achieve a given level of water quality at the least cost. The optimal (least cost) design to achieve each level of water quality is the trade-off comparison which is useful to policy makers as they decide which system design to install in their community.

Amortization Versus Discounting

This study provides decision-makers with some criteria for selection among alternative system designs. In water resource studies, typically the research must take into account the life of the system. This has great implications pertaining to what costs to use for each alternative system and the magnitude of these costs. Amortization, which shifts fixed costs to a flow basis or discounting which shifts fixed and variable costs to a present value are two ways of relating fixed and variable costs of a project. Both procedures are essentially an accounting concept to permit comparison of income streams in different time periods.

The function of amortization is to allocate systematically the cost of fixed assets over their estimated service lives as a "prepaid expense of operation." [19] Amortization of the fixed costs in this study was computed using the installment payment formula:

$$a = \frac{i(1 + i)^n}{(1 + i)^n - 1} \cdot V_o \qquad (2.1)$$

where:

a = amount of an annual payment or annuity that will pay off a specified sum in 'n' equal annual installments.

i = interest rate

n = number of years

V_o = capital sum to be paid off

An alternative approach to the proper relating of costs is the discounting procedure. Discounting calculations are completed on all costs, i.e. fixed capital costs and variable costs of system operation and maintenance. Discounting looks at the present value of costs over the system life through the formula:

$$P.V. = \sum_{t=0}^{n} \frac{A}{(1+i)^t} \tag{2.2}$$

where:

PV = present value

n = number of years

t = time

i = interest rate

A = annual cost

Theoretically, whether one uses amortization or discounting, the economic ranking among alternative systems should be identical. In this study fixed costs were amortized to determine the appropriate annual charge to pay-off installation costs;then annual variable costs were added to give the cost coefficients for the six activities to be included in the computer model.

Specification of the Empirical Model

The determination of the cost of alternative system designs, and the sensitivity of the optimal solution to varying levels of water pollution were accomplished through the use of a pure linear integer programming model. This program was used to examine the effect of varying levels of acceptable environmental pollution parameters on the total system costs of rainfall runoff removal in the case study watershed. This type of program allows only discrete activity levels in the objective function and further stipulates that only one activity is considered per solution.

The general form of the model is as follows:

(1) Minimize $Z = \Sigma c_j x_j$ $j = 1, \ldots, n$

(2) Subject to $a_{ij} x_j \leq b_i$ $i = 1, \ldots, n$

(3) and $x_j \geq 0$ $x_1 \ldots x_p$ $(p=n)$

(4) and $x_j = 0,1$ for $x_1 \ldots x_p$ $(p=n)$

with the notation as follows:

Z = annual system costs amortized over a 50-year period.

x_j = the activities included in the objective function.

a_{ij} = the physical transformation coefficients for each environmental activity.

c_j = the amortized cost of each activity.

p = number of discrete activities.

n = number of all activities.

Allowing activities to be, in essence, zero-one variables was required due to the nature of the cost functions and cost data available for each alternative system. Parametrically ranging the right-hand-side (RHS) values for the environmental constraints allowed an analysis of the responsiveness of water quality to different system costs. Consequently, tradeoff relationships between system costs and the level of water quality could be generated and studied.

The discrete activities contained in the model were various combinations of open channel drainage systems, primary and secondary treatment facilities, and pipelines. Each of the discrete activities identified a different alternative system for rainfall runoff removal. The model objective function was minimized subject to a set of environmental quality constraints. Water quality constraints included in the model were: total solids, suspended solids, chemical oxygen demand, chlorides, and an index which combined these four water quality parameters.

Relation of Model to Theory

With use of the pure integer programming algorithm, continuous cost functions are not taken into account in the model. The model works with only one point for each system cost function, thus the continuity of the production function is not taken into account. Assuming no discounts for larger pipe purchases, the cost function would exhibit constant costs per acre regardless of the size of the watershed. However, the treatment plant variable cost functions exhibit decreasing costs as average flow increases. Therefore, a point on the decreasing portion of this cost function was selected which was consistent with the size of watershed under study.

The interpretation of the trade-off relationship is limited by the use of the integer programming model since continuous functions are not developed. Points are estimated by use of the empirical model to provide a relation between system costs and water quality. A point may be derived on a cost function for each system solution. With several different systems included in the analysis, it is possible to derive several points to compare for each system which enters solution over some range of water quality.

CHAPTER III

PROCEDURES AND DATA BASE

This chapter involves three major topics. The first topic is a brief description of the watershed which was utilized as a case study. The second topic describes the cost coefficients developed for the alternative runoff disposal designs. The third topic involves the description and discussion of the water quality coefficients used in the study.

The Watershed: Case Study [64]

The Ross-Ade Upper Watershed, located north of the Purdue University campus in West Lafayette, Tippecanoe County, Indiana, was selected as the case study area. The climate of Tippecanoe County is continental, humid, and temperate. Warm humid summers and moderately cold winters are characterized by frequent, sudden changes of temperature. Although the range between the average winter temperature of 28.5°F and the average summer temperature of 73.4°F is not extreme, wide variation may occur within a season.

Nearly 60 percent of the average annual precipitation of 38.26 inches falls during the growing season. The average frost-free season at Lafayette is 165 days, from April 27 to October 9. All of the county is within the drainage basin of the Wabash River. The uplands of the county are on the glacial till plain. Except along major drainage ways, the topography of the county has not been greatly changed by stream development since glaciation. The till plain is about 700 feet above sea level while the flood plain of the Wabash River reaches an elevation of about 520 feet.

The watershed area consists exclusively of residential housing. The area has a mean basin slope of 2 percent over a stream length of .6 miles. The watershed encompasses an area of 29.12 acres with an impervious area of approximately 38 percent. The predominant soil type in the area is Warsaw silt loam which has underlying material of water, assorted gravel, and sand. Internal drainage is relatively rapid through this gravel substratum. The upper subsoil is silty clay loam which slows surface drainage in relatively level areas.

Pipeline System Fixed Costs

Total pipe length installed in the Ross-Ade Upper Watershed was obtained by measurement of maps at the West Lafayette City Engineer's Office. The maps show the entire pipe drainage system in the watershed

Table 3.1. Pipe Diameter and Length in Ross-Ade Upper Watershed in West Lafayette, Indiana[a]

Street/Pipe Diam.	8"	10"	12"	15"	18"	24"	Man-Holes
Maywood	375'						0
Garden	876'						3
Elmwood							2
Ravinia	105'	578'					1
Woodland	568'		320'	312'	306'	750'	9
Carrolton		350'	440'				3
Hillcrest		270'	230'	220'			2
Ridgewood	370'						1
Riley Lane	285'						1
TOTAL	2579'	1198'	990'	532'	306'	750'	22
% of Total	40.6	18.8	15.6	8.4	4.8	11.8	

[a] Measurements from West Lafayette City Engineer's Office

area and break down pipe size into several different diameters. Refer to Table 3.1 for these measurements.

Pipe cost data obtained from a local supplier are presented in Table 3.2. Costs are illustrated for the three classes of pipe. The higher the class, the more pressure, in pounds per square inch, the pipe can withstand. After consultation with the city engineers office and the pipe supplier, it was decided that class four pipe would be sufficient for the watershed area under study.

Given the length of all diameters of pipe used and the costs of each diameter, the first step toward calculation of total system costs was completed. The other costs needed to estimate system expenses are manhole costs and costs of installation. The cost of purchasing and installing a manhole is approximately $500, while installation costs can be estimated by multiplying pipeline costs by two and one-half.[1]

Table 3.2. Pipeline Cost Data for Concrete Sewer Pipe with Rubber Gasket, 1970[a]

Pipe Diameter	Class 4	Class 3	Class 2
8"	$1.90		
10"	$2.00		
12"	$2.25		
15"	$3.65	$3.25	
18"	$4.75	$4.20	
24"	$7.55	$6.70	
36"	$15.45	$13.75	$13.50

[a] Quoted prices from Lafayette Pipe

[1] Professional opinion of engineer for the City of West Lafayette

Total system costs for the pipeline system installed in the Ross-Ade Upper Watershed were estimated to be $102,647.11 or $16.15 per linear foot (see Table 3.3). After amortization of these fixed costs, the cost coefficient, c_j, for the urban residential pipeline drainage system will be determined for use in the integer programming algorithm.

Table 3.3. Estimated Pipeline Installation Costs for Ross-Ade Upper Watershed, West Lafayette, Indiana[a]

Item	No.	Per Unit Cost.	Total Cost
Manholes	22	$500	$11,000.00
8" pipe	2579'	$1.90/ft.	4,900.10
10" pipe	1198'	$2.00	2,396.00
12" pipe	990'	$2.25	2,227.50
15" pipe	532'	$3.65	1,941.80
18" pipe	306'	$4.75	1,453.50
24" pipe	750'	$7.55	5,662.50
TOTAL MATERIAL COST			$29,581.40
INSTALLATION CAST			49,453.50
ENGINEERING, LEGAL FEES, ETC.[b]			26,612.21
TOTAL SYSTEM COST			$102,647.11

[a] All pipe is class IV, pipe diameters of 15, 18 and 24 inches may be purchased under class III specification at about a 10% discount to class IV costs.

[b] See Robert Smith, "Costs of Conventional and Advanced Treatment of Wastewater", Water Pollution Control Federation, Vol. 40, No. 9, p. 1560 for a further discussion of these costs.

Open Channel System Fixed Costs

Construction Costs

Open channel design can vary greatly depending primarily on the amount of outflow from the watershed and the area of location. Open channel system costs for an urban area would typically include costs of grading, sodding, seeding, tree removal, and the concrete "channel" in the waterway. Two recent studies have been conducted to estimate the costs per lineal foot of an open channel waterway. However, both studies failed to include costs of land acquisition in the cost formulations.

The Engineering News Record [13, p. 69] cited an example of open channel waterway costs which included charges for sodding, seeding, tree removal, grading, and a concrete riprapped-flat bottom channel. Construction costs were estimated to be approximately $83.00 per lineal foot for the project. This included the channel with 2:1 side slope and a minimum depth of eight feet. Unfortunately, no reference was made to the comparable costs of a pipeline system for the same area.

However, a study conducted by Prawdzik [45] in Milwaukee compared costs of open channel and pipeline systems for a similar area. Open channel costs were found to be much cheaper than a comparable pipeline system which would handle the same amount of runoff. The authors points out reasons for this difference:

> "While cost figures appear overwhelmingly in favor of open channel construction, right of way and other costs could easily reduce the overall advantage and therefore must be taken into consideration." [45, p. 36]

Prawdzik estimated the cost of an open channel 2,500 feet long with a 70 foot wide right of way to be $65.00 per lineal foot. This cost figure included grading, concrete cunnette, sodding, seeding, tree removal, and a minor amount of slope paving. The estimated costs for a comparable pipeline system was $245.00 per lineal foot.

With the comparisons of the two systems referenced in the above study, the estimation of open channel installation costs was possible.

Installation costs were estimated for the pipeline system in the previous section. Assuming a constant ratio between the costs of open channel and pipeline as derived from Prawdzik study, raw costs of installation for the open channel were estimated to be $4.29 per linear foot. This cost was used for derivation of the open channel cost coefficients.

The cost figure utilized in this study is much lower than the figures cited from Engineering News Record and Prawdzik because the Ross-Ade Upper Watershed is much smaller than the other two. Size of the watershed area can be directly related to the runoff. Larger watersheds require wide and deeper channels to drain the runoff in the same amount of time as in a small watershed. The difference in channel width, side slopes, and depth of channel contribute to the difference in the three costs previously mentioned.

Land Costs

Open channel systems differ from pipeline systems in relation to costs because installation costs of an open channel can include land acquisition costs. Pipelines can be installed underground after an easement, at little or no cost, is obtained. Hence, it is probable that municipal authorities might easily encounter extra costs of land acquisition if an open channel system design is adopted.

Prawdzik [45, pp. 21-23] discusses three ways of obtaining legal rights to the right of way desired for the open channel system:

1. Obtaining an easement--where limited right to land for open channel systems are planned and granted by the contractor before a project is developed.

2. Accepting a quitclaim deed--an outright dedication of the land to the city by the owner.

3. By process of condemnation--involves public hearings, court rulings, and can be quite costly to the city.

The first and third of the above alternatives were considered in the research. First, cost coefficients were amortized excluding all land costs. The optimal system solution derived from that procedure will be relevant for city planners and engineers involved with planning an area for future development which requires easements or deeds of drainage areas be made before land development. There is no charge to the public sector for obtaining an easement for this purpose.

The second alternative involved calculation of land costs plus condemnation suit costs to be added to the construction costs and amortized. The optimal solutions obtained in analyzing these type cost coefficients will provide information to public officials contemplating installation of one of these systems in an already-developed area.

Installation of an open channel in the Ross-Ade Upper Watershed would require condemnation of approximately two acres of privately owned land. Land values in the West Lafayette area were found to range from $20,950 to $22,805 per acre.[2] To these market values must be added court costs and condemnation suit awards. These latter costs would include court costs and any possible damage awards by the court. However, it has been estimated that between 75 and 80 percent of private land owners do, in fact, accept the appraised state market value. If damage suit judgments were made, the results of these suits were estimated to be zero for this particular study.[3] Hence, total land acquisition costs will assume that private

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[2] Purdue Research Foundation estimate of land values exclusive of improvements in a West Lafayette area deflated to 1970 prices.

[3] After consultation with an attorney in the area it was decided that damage suit awards would not be included in the model since these awards are quite arbitrary and vary so greatly.

land owners accept the appraised market value of the land condemned. Acquisition costs were estimated to be $21,900 per acre. Converting this figure to a linear foot basis yields a charge of $7.30 per linear foot of channel for land costs.

The total system costs include both the installation and estimated annual variable costs. System operation and maintenance costs will be discussed in the next section.

Costs of Operation and Maintenance of Pipeline and Open Channel Systems

After consultation with the West Lafayette city engineer and the Allen County surveyor's office, it was determined that the variable costs, i.e. costs of operation and maintenance, associated with open channel systems average about 5 percent of installation costs over the life of the project excluding land acquisition costs. Furthermore, it was estimated that variable costs of a pipeline system are approximately 25 percent of the variable costs associated with an open channel waterway.

These assumptions were made in cost calculations for the case study watershed. Little work has been conducted in the area of determination of variable costs associated with either type of drainage system. Therefore, professional opinion by people with years of practical experience in the area was the main source of these data.

Waste Water Treatment Plant Operation and Maintenance Costs

Prior to the construction of water treatment plants, often insufficient or at least inadequate attention is given to the estimation of costs of operation and maintenance. There is little to be gained, at least economically, through careful planning and design unless these new treatment plants are satisfactorily operated. The reasons for the above statement are two-fold: "(1) it is economically unsound to make heavy investments in plants and fail to implement sound programs of operation and maintenance and furthermore, (2) the resulting effluents from poorly managed plants could prove to be more hazardous to public health than untreated water." [49, p. 111]

This section continues a brief review of some of the cost estimation techniques for water treatment plants. The Water Pollution Control Act of 1956 (P.L. 660) allowed federal financial assistance for communities in the construction of water treatment facilities. In this Act, however, there was the stipulation that before financial assistance could be given the community must provide the desired information about operating and maintenance costs. A study conducted by Rowan, Jenkins, and Howells utilized data obtained from the Public Health Service survey to provide estimating equations for treatment plant operating and maintenance costs. [49, pp. 111-121]

Upon completion of the analysis of data it was determined that the inverse function:[4]

$$\log Y = \frac{1}{a + b \log x} \qquad (3.1)$$

where:

Y = annual cost per mgd (million gallon per day) x .001.

x = average daily flow in mgd x 100

would fit the data. This estimation equation gave the smallest standard error of estimate among the several equations tested.

4 Where 'a' and 'b' are known constants with respective magnitudes of 0.49273 and 0.23867 for estimates of annual operating and maintenance cost of primary plants.

The present facilities in West Lafayette had a flow of 5 mgd with a design capacity of 12.5 mgd. The flow of five mgd was used as the entry point for the equation 3.1 above to determine operation and maintenance cost. The calculated costs include both lower and upper limits.

Primary Treatment

The method of primary treatment is to use settling tanks with separate units for the digestion of solids. The primary treatment annual variable costs for the Ross-Ade Upper Watershed were estimated at $352.93. This cost figure was obtained by dividing the total expected cost for primary treatment at a flow rate of 5 mgd derived from equation 3.1 by the acreage served by the West Lafayette treatment plant. This figure was then multiplied by the total acreage in the case study watershed. Cost estimation data in terms of dollars per million gallons per day are presented below in Table 3.4. Note the economies of scale that occur as average flow increases.

Table 3.4. Estimated Operation and Maintenance Cost for Primary Plants[a]

Average Flow (mgd)	Estimated Annual Cost ($/mgd)[b]		
	Lower Limit	Expected Value	Upper Limit
0.1	$12,602	$23,294	$43,094
1.0	5,808	10,736	19,862
10.0	3,635	6,719	12,430
100.0	2,655	4,908	9,080

[a] [49, p. 113]

[b] Valid flow range, 0.1 to 100.0 mgd.

Activated Sludge

"This category included the conventional activated sludge processes plus other types of aerated biological treatment." [49, p. 117] The cost estimation equation for activated sludge was of the form: [49, p. 115]

$$\log Y = \frac{1}{0.40662 + 0.17223 \log x} \qquad (3.2)$$

where: Y = annual cost per mgd x 0.001

x = average daily flow in mgd x 100

The above equation provided an estimate of $653.74 as the annual variable costs for activated sludge treatment on the case study watershed.

High-Rate Trickling Filter

"Trickling filter plants included in this category employ recirculation along with a filter loading rate in excess of 4 mgd/acre, the maximum allowable load for the standard rate filter plants." [49, p. 118] The cost estimation equation for high rate trickling filter plants was found to be of the following form: [49, p. 116]

$$\log Y = \frac{1}{0.36435 + 0.25968 \log x} \qquad (3.3)$$

where: Y = annual cost per mgd x 0.001

x = average daily flow in mgd x 100

This estimating equation gave a value of $404.77 as the annual variable costs for the high rate trickling filter attributable to the Ross-Ade Upper Watershed.

Fixed Costs of Treatment Plants

A study conducted by Shah and Reid [56] was used as the basis for calculation of construction costs for primary and secondary treatment plant facilities. The cost-estimating equations for the Shah and Reid study gave an approximation of the fixed costs (construction costs) associated with various types of water treatment facilities. The previous section's review of the study by Rowan, et.al. gave estimates of the variable costs associated with water pollution, i.e. costs of operation and maintenance.

Primary Treatment

Costs of primary treatment plants can be estimated according to their hydraulic loading. [56, p. 780] The data from a sample size of 103 primary treatment plants was fitted with the highest R value and least error to the following equation: [56]

$$\ln Y = b_0 + b_2 \ln X_2 \qquad (3.4)$$

where:

Y = construction cost per mgd design, in 1957-59 dollars

b_0 = 12.42

b_2 = -0.3852

X_2 = design flow in mgd

Applying this equation to the treatment facilities in West Lafayette, Indiana provides an approximate estimate of the construction costs of a primary plant with a 12.5 mgd design capacity. The estimated cost was $93,000 per mgd design capacity. To obtain the total expected cost in 1970 dollars involved utilizing the WPC-STP Construction Cost Index which has a base year of 1957-59 dollars.

$$93{,}000\ (12.5)\ \frac{138.15}{100} = \$1{,}621{,}535 \qquad (3.5)$$

which represents the total expected cost of constructing a primary treatment plant with 12.5 mgd design capacity.[5]

A more inclusive total cost figure would include facilities such as outfall sewers, administration, engineering and legal services. This may be computed by increasing the above figure by 20 percent. Hence, an estimated cost figure of $1,945,842 (in 1970 dollars) would include all costs except land acquisition.

Activated Sludge

Utilizing the same regression technique discussed earlier in this section the best[6] estimating equation for activated sludge treatment plant construction costs was found to include two variables: [56]

$$\ln Y = b_0 + b_1 \ln X_1 + b_2 \ln X_2 \qquad (3.6)$$

where:

Y = construction cost per design mgd, in 1957-59 dollars

b_0 = 8.53

b_1 = 0.4610

X_1 = design PE

b_2 = -0.7375

---

5 The 138.15 is the national average index value which represents the national average increase in construction costs from the base period of 1957-59 to the year 1970. The index was obtained from a cost index table from the Federal Water Quality Administration.

6 The term "best" in this context means this equation had the highest R-value, was accepted as a result of the sequential F-test, using a 5% significance level, and no evidence of correlation between residuals was found.

X_2 = design flow in mgd.

To present the relationship between organic loadings to be included in estimation equations for secondary facilities, the variable population equivalent, PE, was included in the regression analysis. PE takes into account average waste inflow and average 5-day BOD of waste.[7] Population equivalent (PE) must be calculated for the West Lafayette design treatment plant in order to utilize any of the secondary treatment plant cost estimating equations. Utilizing the PE equation in footnote 7 the population equivalent is calculated as 44,590. Inserting this coefficient in equation 3.6 yields a cost of construction of \$109,370.

The total estimated construction cost in terms of 1970 dollars would be:

$$\$109{,}370\ (12.5)\ \frac{138.15}{100} = \$1{,}888{,}683 \qquad (3.7)$$

This figure represents the total expected construction cost of an activated sludge treatment plant. A figure which would include engineering, administrative, and legal fees would be approximately \$2,266,419. This figure excludes the cost of land.

High Rate Trickling Filter

The final estimating equation needed from the Shah and Reid study for inclusion of costs into the model was that of the high rate trickling filter plant. The estimating equation has the same functional form as

---

7 $PE = \frac{8.33\ QL}{b}$

where 8.33 is a conversion constant, Q is average waste inflow to treatment plant in mgd, L is the average 5-day BOD of waste in mg/1, and b is assumed to be 0.17 lb (0.0771 kg.) which is a measure of BOD per capita per day.

for the activated sludge secondary plant facilities.

Estimated raw costs per mgd design flow were \$105,930. Expected total costs in 1970 dollars would be:

$$\$105{,}930\ (12.5)\ \frac{138.15}{100} = \$1{,}829{,}278 \qquad (3.8)$$

The total cost including engineering, administrative, and legal fees would be approximately \$2,195,133. This excludes cost of land.

Subsystem Costs for Pipeline, Open Channel and Treatment Plants

Table 3.5 summarizes all costs for the case study watershed. This table is a condensation of the costs developed in this chapter. The costs included in this Table provide the basis for the C_j coefficients utilized in the programming model. The estimated fixed costs associated with all drainage activities and treatment plants will be amortized over a 50-year period to provide an estimate of annual payments to pay off the construction cost. Variable costs will then be added to these amortized costs to derive the total cost coefficients for the integer programming model.

Note the interesting relationship between the costs for secondary treatment facilities indicated in Table 3.5. The activated sludge secondary treatment is more costly for the watershed under study than the high rate trickling filter. However, in the United States, approximately 90% of the secondary treatment facilities have activated sludge type treatments. Hence, both activated sludge facilities and a high rate trickling filter system will be included in the model as potential alternative system designs.

Table 3.5. Costs for Conveyance and Treatment Components of System Design in 1970 Dollars: Ross-Ade Upper Watershed.

System Component	Annual Variable Cost per Acre	Annual Variable Cost for Watershed	Fixed Cost Per Acre	Total Fixed Cost for Watershed
Pipeline	$21.81	$635.25	$3524.97	$102,647.11
Open Channel:				
with land acq. costs	87.26	2541.00	2497.25	72,720.00
without land acq. costs	87.26	2541.00	993.13	28,920.00
Primary Treatment	12.12	352.93	622.67	18,132.15
Activated Sludge Treatment	22.45	653.74	712.45	20,746.54
High Rate Trickling Filter	13.90	404.77	702.44	20,455.05

Water Quality Data Sources

Water quality data on open channel and pipeline systems were available from three sources, two of these were studies in the Lafayette area. Table 3.6 illustrates the type of data on water quality parameters that were available from each of these three studies. Work completed in 1969 by Schultz [35] examined pollution differentials in urban, semiurban, and rural watersheds. Data presented for the urban watershed was for a pipeline system, while data given for the other two watershed types were for open ditch systems. To develop a comparison, in the form of trade-off relationships, of alternative drainage systems in a watershed, it is necessary to have both open channel and pipeline data for a particular land use, .e.g. urban residential area. Therefore, Schultz's research did not provide the comparative data necessary for this study.

Table 3.6 Data Sources for Water Quality Coefficients

Water Quality Coefficient	Land Use and System Type							
	Rural		Semi-Urban		Urban Commercial		Urban Residential	
	Open Channel	Pipe-line	Open Channel	Pipe-Line	Open Channel	Pipe-Line	Open Channel	Pipe-Line
TOTSOL	a,b		a,b		a	a	a	a,b
SUSSOL	a,b		a,b		a	a	a	a,b
CHOXDD	a,b		a,b,c		a	a	a	a,b,c
CHLIDE	a,b		a,b		a	a	a	a,b

[a]Data available from Economic System Corp. on Tulsa, Oklahoma.
[b]Data available from Schultz on Lafayette, Indiana.
[c]Data available from McElroy on Lafayette, Indiana.

Similar work completed in 1972 by McElroy [38] set up a sampling methodology for urban and semiurban/rural watersheds. Methodological design was similar to the previous research, hence appropriate comparisons of pipeline and open channel systems could not be made based on these data. The data in the above two studies differ due to the fact that McElroy's study scrutinized the "first flush" effect while the Schultz study did not analyze that effect. This tended to give different values for the sampled parameters.

A study completed by Economic Systems Corporation [12] examined pollution in rural, urban commercial, and urban residential areas. For the latter two categories both open channel and pipeline data were available. Hence, it was possible to compare the differences in water quality between pipeline and open channel systems. The data from this system were used as the environmental coefficients which were then applied to the Ross-Ade Watershed.

The pollution parameters used from the Economic Systems Corporation study were compared to the research by Schultz in the Lafayette area to test for consistency. The parameters of total solids, suspended solids, and chemical oxygen demand were consistent among the two studies. If total solids were higher for the urban residential pipeline system than the rural open ditch system in the Economic Systems Corporation study, similar results were obtained from the Schultz study. The parameter of chlorides differed slightly among the two studies. Table 3.7 presents the data for the West Lafayette and Tulsa watersheds for comparative purposes. The consistency between the Lafayette and Tulsa data suggest that it is appropriate to use the Tulsa environmental coefficients to develop the trade-off relations for the Lafayette watershed.

Table 3.7. Comparison of Lafayette and Tulsa Environmental Coefficients Given in Milligrams Per Liter.[a]

Pollution Parameter	Rural				Urban Commerical				Urban Residential			
	Tulsa		Lafayette		Tulsa		Lafayette		Tulsa		Lafayette	
	OC	PP[b]	OC	PP[b]	OC	PP	OC	PP[b]	OC	PP	OC[b]	PP
Total Solids	592		619		1429	351	1137		680	400		480
Suspended Solids	445		244		1196	221	955		280	234		224
Chemical Oxygen Demand	53		32		107	81	93		65	95		140
Chlorides	13		25		11	10	15		13	13		50

a [12], [55] OC = Open channel and PP = pipeline

b Not available.

CHAPTER IV

ANALYSIS

This chapter is divided into three sections. The first section develops trade-off relationships between the system costs to convey and treat runoff and the level of total solids in the runoff. The second section compares system costs to an index of water quality which includes four water quality parameters. The third section considers the cost of selected alternative types of urban development in the year 2020 in Tippecanoe County, Indiana to achieve a given level of water quality. Interpretation of these results will provide city planners and engineers with a methodology for system selection at the present time given a forseeable shift at some future point in time of watershed density and use.

Figure 4.1 presents an outline of the alternative trade-offs developed in the analyses contained in this chapter. The first section of analysis yielded trade-offs between system costs and the level of water quality in an urban residential area. Initially only one pollution parameter, i.e. total solids, was considered. A total of twelve trade-offs were derived from the available data. These trade-offs involved different rates of amortization, inclusion and exclusion of land acquisition costs for the open channel system, and different secondary treatment facilities. This analysis was conducted for the urban residential area only, illustrated as Section I, Column A & B in Figure 4.1.

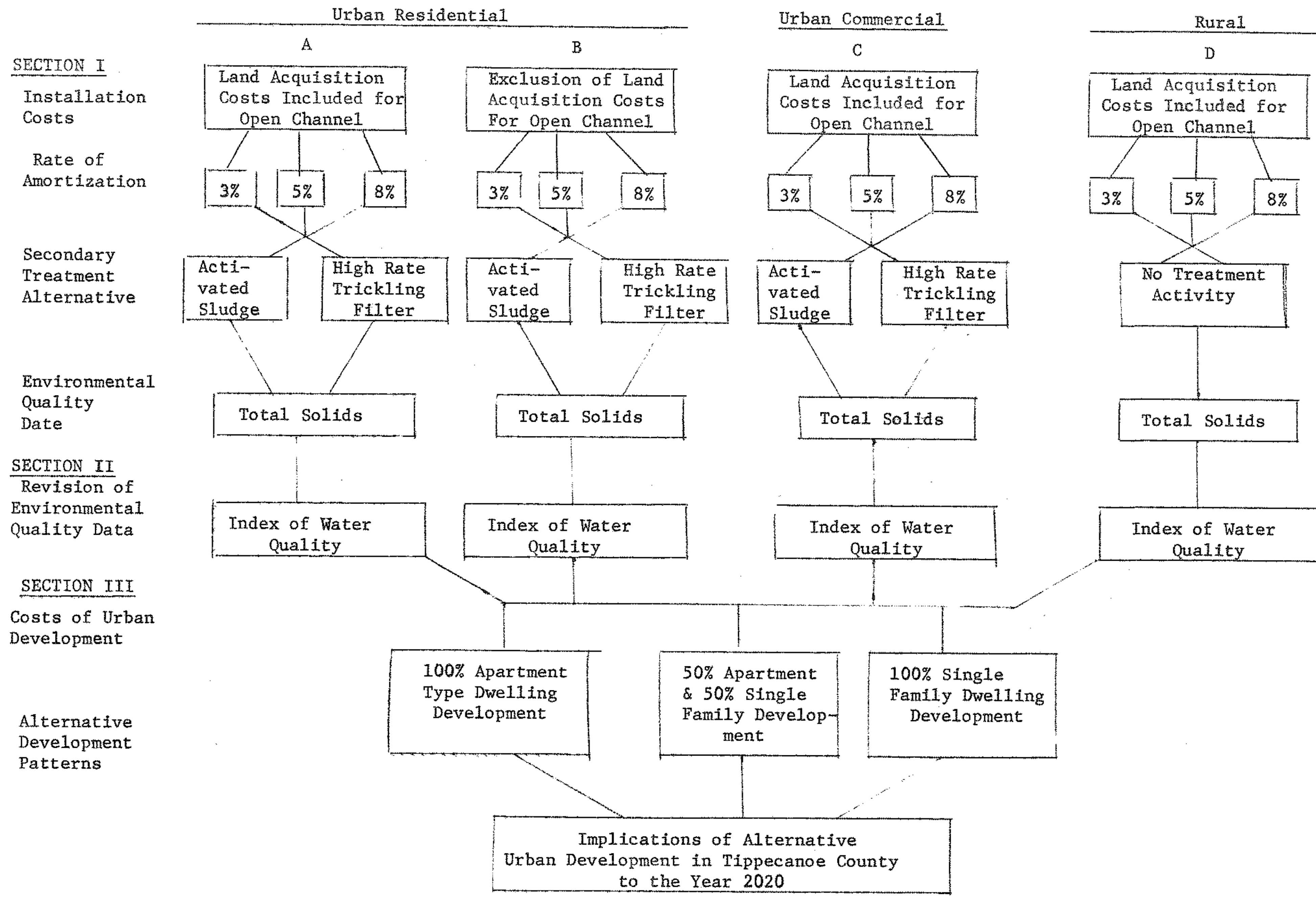

Figure 4.1. Diagram of Alternative Systems Examined to Develop Tradeoff Functions.

The second section of analysis outlined in Figure 4.1 as Section II, Colum A and C included the incorporation of an water quality index into the model to replace the total solids quality index used initially. In this section the pollution parameters of total solids, suspended solids, chemical oxygen demand, and chlorides were combined to give an index of water quality. Trade-offs in this section were presented for Columns A and C. In this case land acquisition costs were included for the open channel system and the secondary treatment facility was activated sludge.

The third section of this analysis examined costs of urban development. Trade-offs were presented which depict systems costs at varying levels of water quality in the urban residential, urban commercial and rural areas. Results from previous sections regarding the urban residential area were used to develop a hypothetical example of future urban development in Tippecanoe County to the year 2020. This part of the analysis was illustrated as Section III in Figure 4.1. Three alternative plans for future urban development were considered, i.e., (1) 100% apartment type dwelling development, (2) 50% apartment and 50% single family dwelling, and (3) 100% single family dwelling development. For a given level of water quality, system cost differentials were examined for the three development alternatives.

To develop trade-offs it was necessary to have data available in one area, i.e. urban-residential, for both the open channel and pipeline systems. Hence, it was impossible to predict trade-off possibilities between system costs and water quality in the rural and semi-urban areas. Furthermore, the data available in both urban areas (commercial and residential) appeared to be of approximately the same magnitude, i.e. if total solids were higher in the urban residential open channel system (U2OC) than in the pipeline system (U2PP), total solids were also higher in the urban commercial open channel system (U1OC) versus the urban commercial pipeline system (U1PP). Therefore, analysis of only one of these two areas was performed since the trade-offs developed for both areas would be similar.

The trade-offs developed illustrate the change in water quality due to a change in system investment under varying characterisitcs. A total of six systems (activities) were included in the integer programming model. Systems were open channel, no treatment (OCNT), pipeline, no treatment (PPNT), open channel, primary treatment (OCT1), pipeline, primary treatment (PPT1), open channel, primary and secondary treatment (OCT2), pipeline, primary and secondary treatment (PPT2).

Urban Residential Trade-Offs for Total Solids Parameter

A total of twelve trade-off possibilities were developed with the use of West Lafayette economic and Tulsa water quality data for the urban residential area. Each program differed in the treatment of amortization, inclusion of land acquisition costs for the open channel system, the type of secondary treatment facilities included in the model, or a combination of the above. This analysis is presented in the four sections below.

Land Cost Included with Activated Sludge

This analysis was conducted to determine how inclusion of land acquisition costs might affect optimal system selection. Activated sludge was included as the secondary treatment facility. The model coefficients are presented in Table 4.1. At the 3 percent amortization

Table 4.1 Urban Residential Total Annual Cost Coefficients with Activated Sludge and Inclusion of Land Costs, Ross-Ade Watershed, 1970.

Amortized Rate and Water Quality Parameter	System					
	U2OCNT	U2PPNT	U2OCT1	U2PPT1	U2OCT2	U2PPT2
3%	$5367.26	$4624.63	$6424.89	$5682.26	$7884.92	$7142.29
5%	$6524.51	$6257.75	$7870.62	$7603.85	$9660.72	$9393.95
8%	$8484.84	$9025.21	$10319.81	$10860.18	$12669.25	$13209.62
TOTSOL(g/s)	931.46	547.92	372.59	219.16	46.56	27.40

rate no open channel system entered solution. Pipeline systems were the more efficient and least costly system over the range of total solids provided by the sampling data. At high levels of total solids the U2PPNT system design was optional. Then U2PPT1 and finally U2PPT2 became the least cost systems to achieve lower levels of total solids.

Costs of TOTSOL removal were found to increase as higher levels of treatment were needed to obtain the desired level of TOTSOL. Shifting from U2PPNT to U2PPT1 resulted in a reduction in TOTSOL level of 329 units at a cost of $3.22 per unit. Further reduction in the acceptable level of TOTSOL was possible at a cost of $7.61 per unit. The higher cost associated with the latter reduction in TOTSOL is due to the higher costs of secondary versus primary treatment.

Amortizing at the rate of 5 percent resulted in essentially a trade-off similar to the one which utilized the 3 percent amortization rate. Again, pipeline systems were the only alternatives which entered as the least cost system design. Costs per unit of removal were somewhat higher due to the increased interest rate. Reduction in TOTSOL due to changing from U2PPNT to U2PPT1 was found to cost $4.09 per unit. The switch from U2PPT1 to U2PPT2 reduced TOTSOL by 192 units at a cost of $9.34 per unit.

Significant solution changes occurred by increasing the rate of amortization to 8 percent. Using the higher amortization rate resulted in the open channel systems entering solution. Comparison of the two no treatment activities, U2OCNT and U2PPNT, illustrated this difference. With the 8 percent amortization rate used, U2OCNT became the least cost activity. Hence, all six activities entered solution at some given TOTSOL level. With use of the lower interest rates, only pipeline systems entered solution since they were the least cost and least polluting alternatives. At the 8 percent level, open channel systems, although remaining environmentally inferior to the pipeline systems, represented least cost systems at some level of TOTSOL. Further analysis of the rate of amortization showed that a rate of approximately 6.8 percent would result in costs of both open channel and pipeline systems being equal to achieve a given level of total solids.

The trade-offs presented above can be depicted in tabular form. Table 4.3 illustrates the systems ordering when the level of TOTSOL is reduced in 50 g/s increments from 1000 to zero.

Table 4.2 System Design Ordering with Inclusion of Land Costs and Activated Sludge, Ross-Ade Watershed, 1970.

Level of TOTSOL	Rate of Amortization		
Grams per Second	3%	5%	8%
950	U2PPNT	U2PPNT	U2OCNT
900			U2PPNT
500	U2PPT1	U2PPT1	U2OCT1
350			U2PPT1
200	U2PPT2	U2PPT2	U2OCT2
40			U2PPT2

Land Costs Included with Trickling Filter

This program yielded systems ordering results for high rate trickling filter as the secondary treatment facility. All other allowed variants in this analysis were the same as Program 3. Model coefficients are presented in Table 4.3.

Results of this analysis were quite similar, as was expected, to the previous analysis with inclusion of land costs of the open channel systems. Table 4.4 depicts the system design ordering when costs were amortized at 3, 5, and 8 percent. The pipeline systems were the only activities that entered solution over the range of total solids available for the analysis at the 3 percent level. The cost of removal per unit of TOTSOL as the feasible solution changed from U2PPT1 to U2PPT2 was found to be slightly lower than the previous analysis using activated sludge as the secondary treatment facility. This cost was $6.26 per unit of TOTSOL removed.

Results of amortization at the 5 percent level were similar to the 3 percent level and consistent with the activated sludge analysis.

The pipeline systems proved to be the least cost and environmentally "best" system solution alternative.

Table 4.3 Urban Residential Total Annual Cost Coefficients with High Rate Trickling Filter and Inclusion of Land Costs, Ross-Ade Watershed, 1970.

Amortized Rate and Water Quality Parameter	System					
	U2OCNT	U2PPNT	U2OCT1	U2PPT1	U2OCT2	U2PPT2
3%	$5367.26	$4624.63	$6424.89	$5682.26	$7624.64	$6882.01
5%	6524.51	6257.74	7870.62	7603.85	9395.81	9129.04
8%	8484.84	9025.21	10319.81	10860.18	12396.49	12936.86
TOTSOL (g/s)	931.46	547.92	372.59	219.16	46.56	27.40

The higher rate of amortization of 8 percent resulted in all six activities entering solution at some point in the range of TOTSOL level. The initial level of TOTSOL was unconstrained, hence allowing U2OCNT to enter the initial solution. The first system to become feasible when the RHS for TOTSOL was ranged downward to become constraining was the U2PPNT. This was the first value of significance in the system ordering presented in Table 4.4. One can draw no conclusions about the initial entry of the open channel system at the unconstrained level since any constraints in the computer routine which were unbinding could be dropped from the analysis and the problem would be that of simply minimization of costs without respect to water quality.

Table 4.4 System Design Ordering with Inclusion of Land Costs and High Rate Filter, Ross-Ade Watershed, 1970.

Level of TOTSOL Grams per Second	Rate of Amortization 3%	5%	8%
950	U2PPNT	U2PPNT	U2OCNT
900			U2PPNT
500	U2PPT1	U2PPT1	U2OCT1
350			U2PPT1
200	U2PPT2	U2PPT2	U2OCT2
40			U2PPT2

As the value of total solids permitted in the runoff was reduced, U2OCT1 entered solution at 500 units of TOTSOL. Open channel systems could enter solution in this particular computer run due to the high rate of amortization and thus the higher costs associated with the pipeline system. However, the open channel systems did not stay in solution over a very wide range of TOTSOL. This is exemplified by the fact that U2PPT1 entered as the least cost system design at a TOTSOL level of 350 units. The results were very similar for the secondary treatment plant system that entered solution.

Land Costs Excluded with Activated Sludge

This analysis was used to derive three different sets of system orderings based on three amortization rates; 3, 5 and 8 percent. No land acquisition costs were included for the open channel system.

Table 4.6 illustrates the systems ordering between system costs and total solid level. Referring to Table 4.5 it can easily be seen that when the right hand side (RHS) value is set at an unconstrained level for total solids, the least cost system in the total solid row will enter solution. The least cost system with costs amortized at 3 percent was U20CNT. Hence, the first point of interest on the systems ordering presented in Table 4.6 for the 3 percent rate was the point where total solids (TOTSOL) equal 950 and system costs were $3664.98.

To develop the ordering for TOTSOL and system costs the RHS was ranged downward in increments of 50 units. Points of interest were points where system design changed, e.g. the second point in Table 4. for the 3 percent rate is where TOTSOL equal 900 and system costs equal $4624.63. A system change occurred with the optimal system now U2PPNT. The change from U20CNT to U2PPNT involved an increased system investment of $959.65 which reduced TOTSOL level by 384 units for a cost of $2.50 per unit.

Table 4.6 Urban Residential Total Annual Cost Coefficients with Activated Sludge and Exclusion of Land Costs, Ross-Ade Watershed, 1970.

Amortization Rate and Water Quality Parameter	System					
	U20CNT	U2PPNT	U20CT1	U2PPT1	U20CT2	U2PPT2
3%	$3664.98	$4624.63	$4722.61	$5682.26	$6182.64	$7142.29
5%	4125.09	6257.74	5471.20	7603.85	7261.30	9393.95
8%	4904.81	9025.21	6739.78	10860.18	9089.22	13209.62
TOTSOL(g/s)	931.46	547.92	372.59	219.16	46.56	27.40

Further ranging of the RHS for TOTSOL resulted in additional changes in least cost system design. U20CT1 entered solution at a TOTSOL level of 500 and a cost of $4722.61. This resulted in a reduction in TOTSOL of 175 units at a cost of $0.56 per unit. At the TOTSOL level of 350 units, U2PPT1 entered solution reducing the water quality parameter by 153 units at a cost of $6.25 per unit.

The last two systems to enter the optimum design involved the higher cost systems which included the secondary treatment activity of activated sludge. The optimal solution changed to U20CT2 at a TOTSOL level of 200 units and cost of $6182.64. This resulted in a decrease in TOTSOL of 173 units at a cost of $2.90 per unit. The final optimal solution was that of the U2PPT2 system. The reduction in TOTSOL level was 19 units with a cost per unit of reduction of $50.09.

Table 4.6 System Design Ordering with Exclusion of Land Costs and Activated Sludge, Ross-Ade Watershed, 1970.

Level of TOTSOL	Rate of Amortization		
Grams per Second	3%	5%	8%
950	U20CNT	U20CNT	U20CNT
900	U2PPNT	U20CT1	U20CT1
500	U20CT1		
350	U2PPT1	U20CT2	U20CT2
200	U20CT2		
40	U2PPT2	U2PPT2	U2PPT2

Review of the systems ordering presented in Table 4.6 for the 3 percent rate analysis presented above illustrates shifts in least cost system design from open channel to pipeline were more costly per unit of TOTSOL removed than shifts from pipeline to open channel systems. This was due to the magnitude of TOTSOL removed in each design change. Although, as Table 4.5 illustrates, the open channel systems are lower cost systems, the TOTSOL levels linked with each system is higher than that of the pipeline system. Hence, though open channel systems do enter solution, the pipeline systems--the higher cost systems--stay in solution over a wider range of TOTSOL levels due to their greater efficiency in handling this type of pollution loading.

For the ordering at the 5 percent rate, pipeline systems failed to enter solution until the TOTSOL level was infeasible for every open channel system, i.e. below 46.56 units. This was due to the wide difference in magnitude of fixed costs associated with each system. Since the fixed costs of the pipeline system were three to four times as great as the fixed costs of the open channel systems, the higher rates of amortization resulted in increasingly greater cost differentials among the two systems. Therefore, the systems ordering presented for the 5 percent and 8 percent amortization rates in Table 4.6 excluded pipeline systems until all open channel systems became infeasible with regard to amount of TOTSOL acceptable. A further reason for the infeasibility of pipeline systems in this particular analysis was the exclusion of all land acquisition costs for the open channel systems.

Land Costs Excluded with Trickling Filter

This set of system orderings was the result of a similar type analysis as in the previous section with the exception of the method of secondary treatment. This analysis was for an urban residential area with no land acquisition costs included for the open channel systems. Costs were amortized at 3, 5 and 8 percent. The final two activities in the analysis U2OCT2 and U2PPT2, were systems which used high rate trickling filter as the secondary treatment facility. Table 4.7 depicts the programming coefficients used and Table 4.8 indicate system ordering for this particular analysis.

The only difference between this analysis and the analysis presented previously was the change in the cost coefficients, c_j's, for the secondary treatment activities. Therefore, the orderings were similar in the analysis to the point where the no treatment and primary treatment activities represented infeasible system solutions.

Table 4.7 Urban Residential Total Annual Cost Coefficients with High Trickling Filter and Exclusion of Land Costs, Ross-Ade Watershed, 1970.

Amortized Rate and Water Quality Parameters	System					
	U2OCNT	U2PPNT	U2OCT1	U2PPT1	U2OCT2	U2PPT2
3%	$3664.98	$4624.63	$4722.61	$5682.26	$5922.36	$6882.01
5%	4125.09	6257.74	5471.20	7603.85	6996.39	9129.04
8%	4904.81	9025.21	6379.78	10860.18	8816.45	12936.86
TOTSOL (g/s)	931.46	547.92	372.59	219.16	46.56	27.40

The cost coefficients associated with the high rate trickling filter secondary treatment facility in this analysis exhibited a slight cost advantage when compared to the activated sludge secondary treatment facility in the previous analysis. However, other characteristics, not considered in this analysis but suggested by engineers indicate that the activated sludge system may be the preferred treatment. The high rate filter analysis was conducted since the objective of this study was to present several alternative system designs and not one of making the choice among them for citizens and planners.

Table 4.8 System Design Ordering with Exclusion of Land Costs and High Rate Filter, Ross-Ade Watershed, 1970.

Level of TOTSOL	Rate of Amortization		
Grams per Second	3%	5%	8%
950	U2OCNT	U2OCNT	U2OCNT
900	U2PPNT	U2OCT1	U2OCT1
500	U2OCT1		
350	U2PPT1	U2OCT2	U2OCT2
200	U2OCT2		
40	U2PPT2	U2PPT2	U2PPT2

At the 5 and 8 percent rates of amortization the ordering of system designs are identical. Intermediate pipeline systems that were in the ordering at the 3 percent level dropped out at the higher rates of amortization. When comparisons were made between the "no treatment" activities in each program, it was evident that the cost differentials between the open channel and pipeline system increased as increasing rates of amortization were applied to the analysis. The reason for this occurrence can be related back to the original magnitude of fixed costs of both systems. The pipeline fixed costs were approximately three and one-half times the fixed costs associated with the open channel.

Index of Water Quality

Computation of a water quality index was undertaken to allow for a broader interpretation of water quality improvement connected with installation of runoff systems with differing treatment levels. It was possible that the total solids criterion alone might have been a unique situation. The use of the index permits a broader test of the generality of the results developed earlier in this analysis.

Other water quality parameters available included: suspended solids, chemical oxygen demand, and chlorides. Program 3 (land costs included with activated sludge) from the total solids trade-off analysis was arbitrarily selected as the design criterion to depict a system cost--water quality trade-off. A weighted index was calculated using values in grams per second for the measured 29.12 acre watershed area. The weighted index was expected to give a more broadly based depiction of water quality since the three new parameters included in the analysis did not exhibit characteristics identical to total solids among the differing system designs. The index, taking more pollution parameters into consideration, should give a firmer basis for judgments about the patterns of trade-offs associated with the six runoff system activities in the integer program.

Although the trade-offs for the 3, 5, and 8 percent rates of amortization are similar to those presented in Table 4.1, the level of these trade-offs differed. A similar set of trade-off functions was found to exist for the urban commercial area. These trade-offs used essentially the same cost coefficients as in the urban residential area, but the water index values, a_{ij}'s for the integer program, differed.

Cost of Urban Development

The previous section of analysis was devoted to an examination of the costs associated primarily with alternative runoff disposal systems in urban residential and urban commercial areas. Land use and population density were assumed to be the same over the life of the runoff disposal system.

In contrast, this section of analysis was designed to illustrate the costs incurred over time as a watershed changes land use and population density. The Ross-Ade Upper Watershed was still used as the case study area. To predict the costs of urban development, it was necessary to initially assume that this 29.12 acre watershed was a rural area. System costs for this area were estimated for an open ditch drainage system. These costs were amortized over the expected life of the project and compared to system costs in an urban commercial and urban residential area. This comparison was made to indicate the type of cost changes that will occur as land use and population density change before the expiration date of the expected life of the project initially installed. An example of this comparison would be the study of a rural watershed with open ditch drainage installed in year 't' with an expected life of 't + 50'. Suppose this watershed is located on the edge of an urban area which exhibits rapid expansion. The question city planners and engineers must deal with is: If the watershed area is expected to be semiurban in 5 years and urban in 15, should it be treated as a rural area with installation of an open ditch or, conversely, should installation of a pipe system be considered which would not be fully utilized for 5 to 10 years?

Table 4.9 illustrates the cost and water quality data similar to those social planners must consider when attempting to deal with situations as posed in the above example. Costs for the urban residential area are identical to the costs amortized at 5 percent in Program 3 (land costs included with activated sludge) of the index analysis. Thus, in conducting the present analysis it was necessary to arbitrarily select an optimal system design for each of the three areas of varying land use and population density. The water quality coefficients represent flow data and were derived from the water quality index developed in the previous section.

Table 4.9 Total Annual Cost and Water Quality Coefficients for Areas of Differing Population Density and Land Use, Ross-Ade Watershed, 1970.

Costs and Water Quality Coefficients	Land Use		
	Rural	Urban Commerical	Urban Residential
Costs	$1577.84	$6257.74	$6257.74
TOTSOL (g/s)	583.71	841.30	547.92
SUSSOL (g/s)	438.77	530.86	320.12
CHOXDD (g/s)	52.26	193.58	129.99
CHLIDE (g/s)	12.82	23.30	17.94
Index (g/s)	492.93	646.66	413.31

The rural open ditch cost coefficient was set at the lowest cost figure since this system would include low land acquisition costs and low installation costs relative to the other systems.

With the data available in Table 4.9 it was possible to examine the costs involved with shifts in land use of a given watershed area and the penalty charges for not taking these changes into account. In year 't' an open ditch system was installed in the watershed even though this watershed was expected to become an urban residential area within the next eight, 't + 8' years. What are the penalty charges to society for ignoring this future shift in land use of the watershed?

For the first eight years the watershed incurred costs to society which amounted to $1577.84 per year, i.e. fixed costs of $977.84 and variable costs of $600.00. With the shift in land use to urban residential in year 't + 8' however, the watershed would incur both the fixed costs of the open ditch system and the fixed and variable costs of the new pipeline system. The extra costs of the open ditch which are still charged to the watershed were the penalty to planners and society of not taking into account the future shifts in land use.

The total "penalty" charges would amount to $41.069,28, i.e. forty-two years of fixed cost charges since the system was designed and amortized on a 50-year basis. The extra costs of installation of the pipeline system eight years earlier would amount to $37,439.20, i.e. eight years multiplied by the difference in costs of the rural open ditch and urban pipeline system.

It is interesting to note that if the land use change were not expected until 't + 9' the open ditch installation would have been the proper decision in year 't'. The total "penalty charges" would amount to $41,069.28, while the extra costs of the pipeline system over the nine years would amount to $42,119.10. This illustrates the fact that planners must be very cognizant of the costs of different drainage alternatives and also have an understanding of the time period over which future development will occur.

<u>Comparison of Differing Types of Urban Development</u>

Unlike the initial analyses with total solids where comparisons and trade-offs or system orderings were calculated in only one area, this analysis provides a framework for comparison of system costs and water quality among all three areas: rural, urban commercial, and urban residential. This analysis provides the framework for comparisons of differing types of urban development.

This type of analysis required some restrictive assumptions. However, the results should aid appropriate public and private personnel by indicating a type of decision methodology appropriate for future policy programs involving installation of drainage systems. It was initially assumed that by the year 2020 the population of Tippecanoe County would reach 200,000 people. From 1970, this would amount to an additional 90,000 people being located within the county boundaries. It was further assumed that two-thirds or 60,000 of these people would reside in subdivision developments that would create runoff with the characteristics of the urban residential areas described earlier in this study. The remaining population increase of 30,000 would reside in either open rural areas or in urban redeveloped areas which would not require installation of new wastewater disposal systems.

Three methods of future development were considered in this analysis, i.e., (1) 100% single family dwelling development, (2) 50% single family dwelling and 50% apartment dwelling development, and (3) 100% apartment dwelling development. It was recognized that alternatives 1 and 3 outlined above would probably never occur, however, differences in modes of future development can best be characterized by use of these extreme cases. Treatment plants would be required to provide adequate reduction in pollution parameters. The differences to be analyzed in this section are those of partial extra system costs of each type of development. Comparative drainage system average annual costs for alternative urban development patterns are presented in Table 4.10.

Table 4.10. Total Annual Cost for Additional Surface Drainage Systems in Tippecanoe County for Alternative Urban Development Patterns Until 2020.

Water Quality Index	Development Design		
	100% Apartments	50% Apartments 50% Single Family Dwellings (S.F.D.)	100% S.F.D.
413	$23,746	$162,712	$302,089
165	$27,512	$200,210	$407,386
20	$34,988	$262,972	$564,641

It was assumed the single family dwelling subdivision development would have 3 1/3 lots per acre with an average of four inhabitants per lot. To accomodate the additional population in this urban area would require acquisition of 4,285 acres of rural land for urban residential development. Total additional costs for a pipeline system including necessary treatment plants to provide water of a quality index of 413 would be approximately $302,089.10 per year over the next fifty years to accomodate this expanded area of service. Note should be made that this cost figure is an estimated average annual cost calculated by dividing total cost by 50 years. This permits a discussion of comparative cost without including the additional variable of rate of amortization. This cost assumes development of subdivisions of approximately thirty acres in size with 105 homes per subdivision.

If urban development in the future was totally single family dwellings, it was assumed a new treatment plant of similar size to the present facility in West Lafayette would be required or it would be necessary to build a new, larger plant to handle the total population in the year 2020.

The second method of development allowed for an even mixture of single family and apartment (or condominium) dwelling development. The assumptions regarding the apartment dwelling were arbitrary since the number of floors per dwelling directly affected the population density per acre. It was assumed that the apartment type development would accomodate, on the average, 45 units per acre with four people per unit or 180 inhabitants per acre.

With the allowance of an equal distribution of apartment and single family residences, the required acreage for this method of development was 2,308. Assuming the pipeline system would be installed in this area, the total surface drainage costs were calculated to be $162,712.15 average per year for the next fifty years. This area could, most probably, be serviced by moderate expansion of the existing treatment plants in Tippecanoe County.

The final alternative in this analysis was that of 100 percent apartment development. Using the same assumptions as in alternative 2, i.e. 180 people per acre, the increase in population to the year 2020 could be located on 333 acres. With similar pipeline costs as in the previous alternatives, the extra costs associated with this development would average $23,476.23 per year to the year 2020. The current treatment plants in Tippecanoe County should prove adequate to treat the stormwater runoff from this additional acreage.

Unlike the previous section of analysis, this section was designed to compare differing types of urban development and present implications of this development on future costs and water quality levels. It is based on the trade-off functions developed previously in this chapter. Certainly there are many other alternative development patterns open to city planners and engineers. Certainly more detailed studies of the probable location of these developments would be necessary to refine the rough comparative costs presented here. However, this analysis does provide a framework for other alternative comparisons of urban development.

CHAPTER V

SUMMARY AND CONCLUSIONS

The Problem and Objectives

Citizens and planners alike face the dilemma of choosing among alternative rainfall removal systems to serve present and future generations. Both system costs and the level of water quality are important system characteristics considered by citizens as they select among alternative system designs. This study compares the relationship between economic system costs and the level of water quality for rainfall runoff removal systems.

This study compared six systems of rainfall runoff removal. These six systems were different combinations of pipeline and open channel transport systems and primary and secondary water treatment systems. Although there are many other alternative systems or combinations of systems which could have been analyzed, these six provided the opportunity to develop a broad planning methodology and analyze costs and quality over a wide range of systems. In practice, the decision of what level of water quality is deemed acceptable is made through interaction of citizens and government officials. Ideally, citizens and elected officials convey their desires to the appropriate agency for implementation. The work presented in this research with regard to the trade-off between economic costs and water quality develops the relation between these two variables. When that information is presented it is the job of the public and of planners to attempt to choose the combination of economic cost and water quality which will, in effect, optimize social welfare or social well-being.

The first objective of this study was to develop an empirical model which would aid citizens and planning officials in choosing among alternative runoff transport and treatment systems. This objective was accomplished through the use of a pure integer type programming model. The objective function, which was minimized, was the amortized yearly costs associated with each of six different runoff removal systems. The activities included both pipeline and open channel systems each with treatment alternatives of: (1) no treatment, (2) primary treatment, and (3) primary and secondary treatment. Constraints in the multiple objective programming model were water quality coefficients associated with each of the six activities.

The second objective was to estimate trade-off possibilities between economic costs and water quality using the alternative system designs. Trade-offs for the Tippecanoe County area were derived with the use of the pure integer program developed in the first objective. These trade-offs depict the economic costs of improving the level quality which was illustrated by a water quality index. Values along the trade-off functions were obtained by requiring progressively higher levels of water quality in the watershed area and examining the cost of system design at each level of water quality. This process is analagous to the functioning of planners who must examine different system cost levels in an attempt to stay within a given budgetary constraint and then, to determine if the level of water quality associated with that specific system cost is acceptable.

The water quality index was developed by taking a weighted average of several water quality parameters. The use of the index values gives a better overall picture of actual quality of the water associated with each system design than would the use of just one pollution parameter.

Trade-off possibilities were calculated for the urban residential and urban commercial areas. The activities incorporated in the model facilitated use of these two areas since rural areas typically do not include treatment plants as a feasible activity and semiurban areas typically have a mix of system designs.

A total of twelve trade-offs were developed for both the commercial and residential areas. Variables which allowed the trade-offs to show different system solution values were (1) different rates of amortization, 3, 5, and 8 percent, (2) different methods of secondary treatment, activated sludge versus high rate trickling filter facilities, and (3) inclusion or exclusion of land acquisition costs for the open channel systems. The development and presentation of these trade-off possibilities completed objective number two.

The third objective provided information to citizens and planners about costs and water quality differentials over time as a watershed shifts in population density and land use. This analysis utilized conclusions made in the second objective regarding system costs and water quality. This objective assumed a specific optimal design system for the future and examined the policy implications of alternative future development. Future policy questions regarding system costs and environmental quality were examined when a rural watershed shifted to an urban single family dwelling versus an urban apartment dwelling watershed.

In summary, this research focused on the following objectives:

(1) To illustrate a design comparison model which will aid city planners and engineers in choosing among differing rainfall runoff transport systems.

(2) To develop trade-off relationships between economic costs and water quality for alternative stormwater systems.

(3) To examine the impact of alternative urban development in Tippecanoe County on the cost and water quality of stormwater removal systems.

Methodology

System costs and water quality were used in this study to develop the trade-off relationships mentioned in the second objective. System costs were used since they are a measure of the sacrifice society is willing to make to derive a "better" level of environmental quality. To account for the entire life of the particular drainage system under study, amortization of fixed costs to an annual basis was used.

The theory of production related costs to the production function and the production function to the total cost function or trade-off function. The trade-off function illustrates the sacrifice in economic efficiency (measured in dollar cost) necessary to improve the quality of environment. The system costs utilized in this case study represent only selected points on the theoretically continuous cost function.

The programming model used for the analysis was a pure integer program which is a special class of the linear programming problem. The pure integer form allows only the inclusion of one activity per iteration, i.e. only one runoff removal system could enter solution for each value of the water quality index constraint. The model actually represented a multiple objective type of planning model with economic efficiency (costs) as the objective function and environmental quality included in the constraint set.

Data

A case study approach was undertaken in the research. The case study area was the Ross-Ade Upper Watershed located in West Lafayette, Indiana. This 29.12 acre watershed was used to examine the differences in environmental quality and system costs associated with the pipeline and open channel methods of rainfall runoff removal.

The Ross-Ade Upper Watershed was measured to determine the total length and diameter of pipeline or open channel waterway which would be needed to drain the area for a rainfall intensity of the magnitude of a 50-year storm. A local supplier provided pipeline cost data for the analysis. Secondary publications provided a basis for the open channel installation costs.

The cost coefficients, c_j's, represent the annual amortized fixed costs of the design system plus the annual variable costs of operations and maintenance. Three sets of cost coefficients were associated with each design system since three amortization rates were used for each system. This enabled examination of the sensitivity of the optimal design system to the interest rate.

Treatment plant fixed and variable cost data were found in secondary sources and incorporated, where appropriate, into the cost coefficients for each activity. To determine if land acquisition costs provide a deciding factor in the selection of an optimal system at a given level of the environmental quality index, these costs were included in some of the computer runs and excluded in others.

The transformation coefficients, a_{ij}'s, of the programming model, which link the objective function and the constraint set were derived from data on a Tulsa, Oklahoma watershed study. This secondary source provided water quality measurements in a stock concept, i.e. milligrams per liter. These coefficients were then converted to a flow type concept through the use of the rational method engineering formula which converts stock to a flow per unit of time.

Empirical Analysis

The first section of analysis resulted in the display of trade-off relationships for the urban residential area. Different design alternatives were considered in the programming model to assess varying land acquisition costs, rates of amortization, and the type of secondary treatment facility. The first six programs analyzed included costs of land acquisition for the open channel alternative. They differed in their incorporation of the secondary treatment activity and the rate of amortization. With either secondary treatment, the pipeline systems were the least cost and least polluting systems at the 3 and 5 percent rates of amortization. At the 3 percent rate of amortization with the activated sludge facility, the pipeline no treatment alternative entered solution at an unconstrained level of total solids. As acceptable total solid levels were constrained below 550, the pipeline primary treatment alternative entered solution at an annual cost of $5682.26 for the Ross-Ade Watershed. When the level of total solids was reduced below 200, the pipeline primary and secondary treatment alternative entered final solution at an annual cost of $7142.29. However, at the 8 percent rate, the three open channel activities entered solution over a limited range of the total solid constraint. This situation illustrates how optimal system design can be sensitive to the interest rate.

The second part of the total solids trade-off analysis deleted land acquisition costs from the model. The six programs analyzed in this part included the three rates of amortization and two types of secondary treatment. When land acquisition costs are excluded the open channel systems predominantly enter solution over the range of total solids and treatment activities available. At the three percent rate of amortization, there is a trade-off between pipeline and open channel systems. However, with use of increased rates of amortization, the open channel system proved to be the least cost systems. This was due to the high fixed costs associated with the pipeline system. At the 8 percent rate of amortization for both secondary treatment facilities, the open channel, no treatment activity entered solution at an unbinding level of total solids.

Usually the open channel treatment facilities entered solution as the level of total solids acceptable in the drainage system was decreased. The only exception to the general pattern of results occurred at very low levels of total solids. This occurred because the pipeline combined with secondary treatment exhibited less pollution loading than the open channel waterway. Hence, as total solids acceptable decreased, open channel systems became infeasible with the pipeline system the only alternative at such constrained levels of total solids.

The second section of analysis utilized a water quality index as a measure of pollution loading. This analysis was similar to section one because it used different rates of amortization, but more restrictive in nature due to the fact that land acquisition costs were included in the model and activated sludge was chosen as the secondary treatment activity. Trade-offs using the water quality index for the urban residential area proved consistent with the trade-offs derived in section one where total solids were used instead of the quality index.

The third section of the analysis about the future development of Tippecanoe County required the addition of a rural area to the above analysis of urban commercial and urban residential areas. For accurate comparison of the three areas it was necessary to assume a 50-year design system would be installed in a rural area, identical to the storm design of the two urban areas. The difference in the internal coefficients of the integer program reflect the difference in pollution loadings among the different areas and are partially attributable to one variable--the runoff coefficient. This coefficient is highest in magnitude for the commercial area and lowest for the residential. The environmental index associated with the rural open channel system design was 492.93. The cost coefficient for the rural open channel system was calculated to be $1,577.84. Hence, in comparisons of the three areas, the rural open channel design was the cheapest and exhibited less pollution loading in terms of flow than the urban commercial area. The great differential in systems costs are due mainly to the lower land acquisition costs in the rural than in urban areas.

With trade-offs developed for the three areas of varying land use and population density, it was possible to deal with policy questions in attempting to interpret the implication of these trade-offs. Three alternatives for future development were established to determine the affects of each on future system costs. The three alternatives included apartment, single family dwelling, and a mixture of the two. It was assumed that by the year 2020, the population of the Lafayette-West Lafayette area would be 60,000 larger than the 1970 population.

Results of the analysis illustrated that for a given level of water quality the 100 percent apartment dwelling development to the year 2020 would exhibit the least average annual system costs to society. This development required acquisition of an additional 333 acres of rural land at an average annual extra cost of $23,476.23. Treatment of this additional acreage through primary and secondary facilities was estimated to add $34,988.04 per year to the current costs of drainage in Tippecanoe County.

The single family dwelling development was estimated to require an additional 4,285 acres for future urban development. Due to the tremendous increase in acreage to be drained, the no treatment alternative was estimated to be an additional $302,089.10 per year for this acreage. Treatment through the primary and secondary facilities would cost $564,641.32 a year for the additional 4,285 acres.

The wide differences of system costs among the two alternatives was caused primarily by the great difference in additional acreage required for each development pattern. The apartment dwelling development probably could be handled by the existing treatment facilities in Tippecanoe County. Hence, additional costs to society were pipeline installation and variable treatment costs. The single family development alternative, however, would require either a new treatment plant to handle the additional large volume of rainfall runoff or major expansion of the existing facilities. Hence, additional costs of this alternative represent piping of a much larger area and increased variable costs and fixed costs for treatment facilities.

Limitations of Research

Certain aspects of this study relating to model formulation and data procurement serve as limitations to the analysis and conclusions. The use of the case study approach fails to provide general information but instead looks at the specific problem in a specific area. The result is that the conclusions and policy implications of the study tend to be useable only for that specific area. However, it is possible to use a similar procedure in other areas to provide a similar decision criteria for rainfall runoff removal systems. Hence, the model used in this study could be utilized for similar analyses on other watersheds with different coefficients. However, the system cost solutions are unique to the West Lafayette area.

Due to the lack of useable water quality data for the West Lafayette area, a Tulsa, Oklahoma study was used to provide the environmental quality coefficients for the model. However, the comparison of the Tulsa data to the water quality data available from the Lafayette area showed remarkable consistency between the two areas. Therefore the water quality coefficients used in this study should serve as an indicator of the magnitude of environmental quality associated with each system.

Some limitations of the empirical model exist. The assumption that only one system would be used for the case study watershed is quite tenable. However, when the analysis was expanded to include the entire Tippecanoe County area, this assumption may prove untenable. Another limitation concerns the static nature of the analysis, since the future flow of costs may not be constant as is assumed in this study. The model did not take inflation into account which would further limit conclusions about appropriate system costs. Also the model assumed amortization rates of 3, 5, and 8 percent were relevant rates of discount.

The use of Tulsa data for the West Lafayette watershed has already been discussed as a limiting factor for interpretation of conclusions and policy implications. Certain other data limitations concern estimates of some of the system costs. Estimates of some installation costs for the systems are based somewhat on either standard calculations or professional opinion judgments.

A paradox exists between the use of stock or flow type data. Comparisons of the rural, urban commercial and urban residential areas show the rural area to be the "worst" polluter in terms of milligrams of pollution per liter of water. However, when these stock coefficients are converted to flow coefficients, the "worst" polluter is the urban commercial area. For this study water quality was measured in grams of pollution per second passing from the watershed area. It was assumed for this study that the flow data was the most relevant for use by citizens and social planners.

Possibilities for Further Research

A comparison of the results of this study to results of a study which used environmental quality data for runoff systems on a national basis could prove useful. The limitations, using a national basis for data, of the case study approach would be circumvented.

Additional systems of rainfall runoff removal could be incorporated in the existing empirical model presented in this study provided adequate data exists. This would give public officials, planners and citizens a broader base on which to make decisions about appropriate system design with regards to costs and water quality.

Civil engineers are currently conducting water quality studies in several watersheds in the West Lafayette area. When these data become available, a similar study could be conducted contrasting results using the West Lafayette and the Tulsa data.

There has been little economic analysis of the operating and maintenance costs associated with different methods of transporting runoff. These records are often available from the municipalities, but no statistically reliable sample of maintenance and operating costs have been prepared to permit accurate comparison of the systems. It would be necessary to obtain these records during a sufficient period of time so that the irregular maintenance costs would be included in the analysis. The value of this economic research would be in identifying exact system operating and maintenance costs so that differences among systems could be incorporated in the system design and selection stage.

The preliminary work on holding ponds as a part of optimum system design is encouraging enough to suggest that further analysis of this subsystem should be explored in additional research. From a cost standpoint and a hydrologic flow standpoint the use of holding ponds in overall system design suggest many intriguing possibilities for further exploration.

It is important to assess the benefit functions related to each of the systems developed in this research. The value of flood damage reduction that occurs as model design specifications change may result in the selection of an optimum solution which is not the minimum cost system. This should be explored in further research.

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