COST EFFECTIVENESS OF ALTERNATIVE SEWAGE COLLECTION TREATMENT AND DISPOSAL SYSTEMS AT RECREATIONAL AREAS

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ABSTRACT

This paper illustrates the applicability and usefulness of systems approach in evaluating the sewage collection, treatment and disposal alternatives at a selected recreational area. The paper identifies the interactions among sewage collection, treatment and disposal alternatives. The anlysis process considers increases in effluent loading rates with additional developments of the project over time and is designed to select the least cost combination of collection, treatment and disposal facilities. The model, as developed in this study, is general; that is, it can be applied to other interactive sewage projects where land application may be beneficial.

INTRODUCTION

Inadequate treatment of sewage from a recreational area may result in serious pollution of streams and groundwater. The common practice of sewage treatment in recreational areas is to use individual treatment unit such as septic tank. Very often these individual units do not operate efficiently due to adverse soil and climatic conditions. Some of the numerous recreational areas with potential pollution problems are: i) Grandview Lake, Indiana (15); ii) Clifton Park, New York (3); iii) Saratoga Springs, New York (1); iv) Prince's Lake, Indiana (16); v) Cordry-Sweetwater Lake, Indiana (16).

Disposal of sewage effluent via irrigation provides additional treatment by removing excess nutrients that are potentially damaging to the environment. Land application of treated or semitreated effluent has recently attracted increasing interest. Irrigated vegetation was estimated to have significant uptake of phosphorus and nitrogen in a Penn State Study (18). Use of effluent for irrigation in state parks or golf courses has not caused any substantial or discernable change in groundwater or downstream surface water quality (6, 14).

In areas where waste effluent has been tried for irrigation, the typical method of application is either sprinkler or row irrigation. However, sprinkler irrigation of shade trees and lawns has been compared to sub-irrigation in this study. The major technical problem of sub-irrigation is emitter plugging.However, plugging may be controlled to large extent by extensive manual and automated filtrations and periodic acid flushing of the lines (14).

The feasibility of using effluent for irrigation depends on the interacting relationships among seasonal population, soil characteristics, topography, climatic factors, comparative costs of sewage collection, treatment and irrigation, and types of vegetation to be grown within the constraints of waste disposal standards. The purpose of this paper is to illustrate the versatility of systems approach in identifying these interacting relationships and to determine the least cost decision rules.

Sewage treatment alternatives compared in this study are i) primary treatment plant, ii) stabilization pond, iii) high rate trickling filter plant, iv) standard rate trickling filter plant, v) activated sludge plant, vi) extended aeration or contact stabilization package plant and other relevant combinations of these treatment alternatives.

Alternative sewage collection systems evaluated in this study are i) conventional gravity flow collection system equipped with lift stations, and ii) pressurized collection system composed of grinder and booster pumps. Pressurized sewer is a recent innovation in sewage collection technology. This method can use smaller diameter pipes than conventional gravity flow system and overcomes problems of land contours which are often encountered in recreational areas.

In conjunction with these collection and treatment alternatives, sprinkler irrigation of shade trees and grassed areas is compared with low pressure underground trickle or drip irrigation, i.e. sub-irrigation.

THE SYSTEM AND ITS COMPONENTS

Basic components of the system under study are illustrated in Figure 1. The specific methodology is to simulate the number of visitors, sewage flow, rainfall, panevaporation, soil moistures and irrigation requirements on daily basis for a period of twenty years for various feasible combinations of dicision variables at different assumed rates of developments. Various major components of the system are defined in the following discussion.

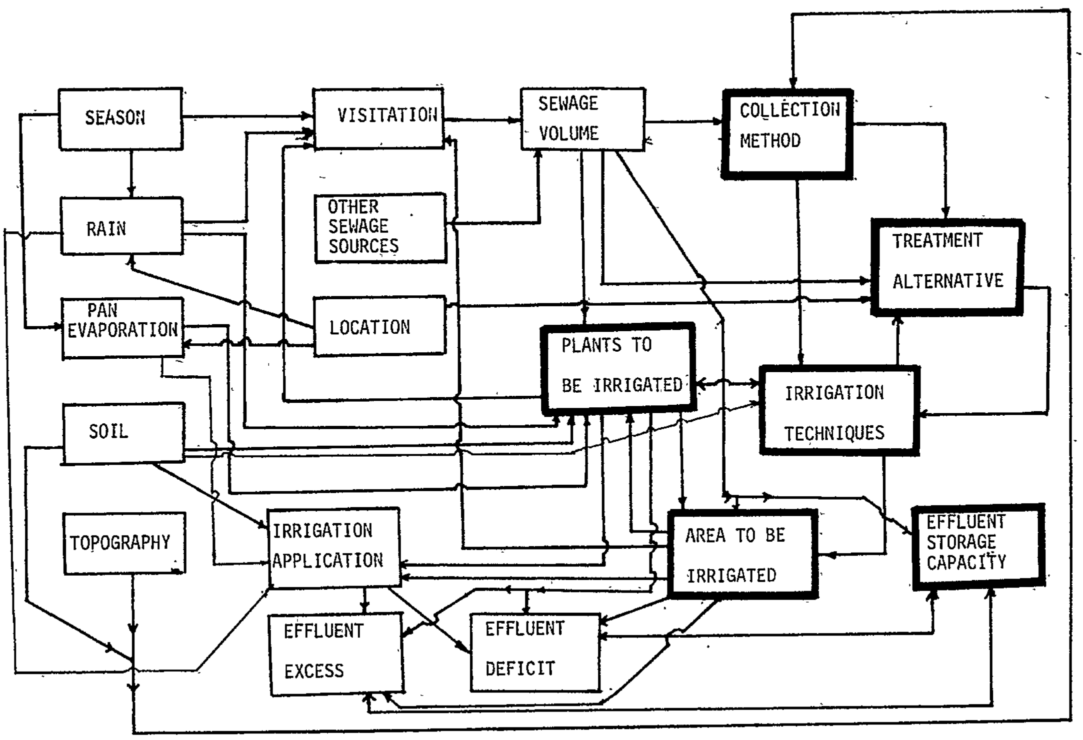

Figure 1. Schematic Diagram of the System

Number of Visitors

Figure 2 illustrates the methodology employed in this study for estimating the number of visitors in any given day. This component of the system estimates the number of visitors at various recreational facilities such as at vacation homes, campgrounds, water ski, fishing or boating sites.

Sewage Volume

The procedure developed in this study for estimating daily wastewater flow at a recreation area is shown in Figure 3. Sources of sewage have been classified into three major categories. First, facilities like campgrounds, visitors centers, trailor parking lots, or vacation homes tend to produce variable amount of sewage depending on the number of visitors at these facilities. Second, sources like employee apartments, office buildings and water treatment plant, if any, account for a relatively stable component of wastewater flow over a period. Third, the infiltration of groudwater or rainwater into the sewer can be a major component of sewage flow.

Collection Methods

Sewage collection system design and its costs, as shown in Figure 4, depend on sewage volume, soil characteristics, topography, infiltration and spread of sewage sources. Since all of these factors are related to the physical characteristics of a specific site, no general methodology can be specified for estimating the collection system costs. On the other hand, this part of the model needs special attention in designing the alternative collection systems specifically for the site under consideration at various assumed rates of developments in the planning period. In this study, collection system cost curves have been developed as functions of future developments of recreational facilities at the case study area.

Treatment Alternatives

The purpose of this submodel is to incorporate the costs and pollutant removal efficiencies of various treatment plant alternatives in the analysis process for identifying the most economic collection, treatment and disposal decision. Standard cost estimation techniques, as available in literature (5, 8, 10, 13, 17), have been used to simulate various cost items associated with the treatment alternatives. The WPC-STP index has been used to adjust the estimated cost figures for a specific construction site. The U.S. Department of Labor's estimates of average earnings for nonsupervisory workers in water, steam and sanitary systems have been used to update various components of operation and maintenance costs.

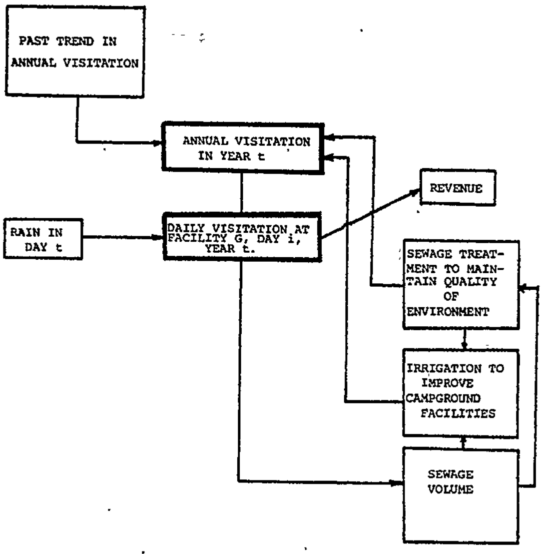

Figure 2. Schematic Presentation of Submodel 'Visitation'

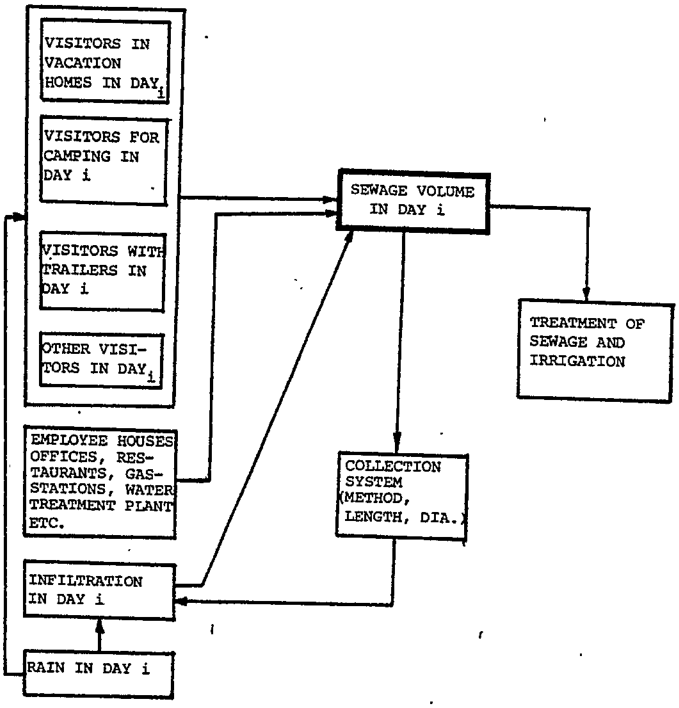

Figure 3. Schematic Presentation of Submodel 'Sewage Volume'

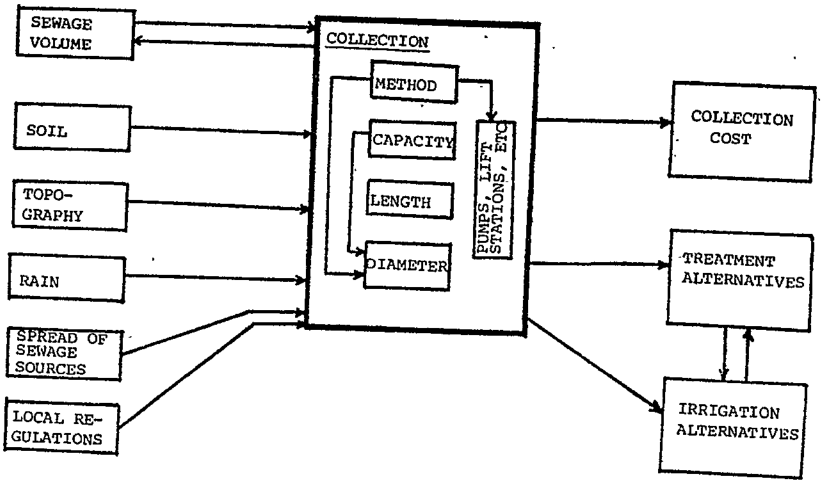

Figure 4. Schematic diagram showing various inputs, outputs and feedbacks in the sewage collection component.

Soil Moisture Balance

Relationships among various components of the model that affect the irrigation system including rainfall, panevaporation, soil properties, plant types, effluent storage capacity are explained by this soil moisture balance submodel. This submodel has been designed to keep a daily account of soil moisture variation in the irrigated fields. This also provides an optimum irrigation schedule. Operating rules have been employed in the simulation model to dispose off excess treated effluent outside the system when storage facility is full and the irrigated areas are at field capacities. On the other hand, this submodel estimates the amount of water to be pumped from the lake when the effluent flow and the volume of previously stored effluent is insufficient to meet the irrigation needs. Detailed concepts of soil moisture balance are available in (2, 9, 20).

APPLICATION

The study area selected for application of the conjunctive model for sewage collection, treatment and irrigation systems analysis is White River Lake, located approximately 45 miles west of Lubbock, Texas. The lake has a surface area of 2400 acres and a capacity of 47,000 acre feet at full lake level. There are approximately 25 miles of shore line. Primary use of White River Lake is municipal water supply. However, there is a shortage of water-based recreational areas in West Texas and this lake has high potential for recreational developments because of its proximity to a growing metropolitan area. The Water District has leased 252 lots for second home developments along the lake shore. These homes are serviced by individual septic tank installations.

Soil adjacent to the lake are not suitable for septic tank drainage fields. The drainage fields generally slope steeply towards the lake. Although no cases of septic tank pollution in the lake have been reported , the Water District responsible for lake development is discouraging further second home developments until sewage treatment facilities are improved.

The area surrounding White River Lake is currently barren except for scattered mesquite bushes. The provision of shade trees and/or grassed areas would greatly enhance recreational.

Simulation Inputs

Installation costs and present worths of operation and maintenance costs for relevant collection, treatment and irrigation alternatives are illustrated in Figures 5, 6, 7, and 8.

Past records of daily rainfall and panevaporation were analyzed to construct respective submodels. Each year was divided into twelve monthly periods. As indicated by modified Spearman's Rho test, daily rainfall and panevaporation values were assumed to be uncorrelated. Daily panevaporation for each of the monthly periods were found to be random from Wallis Moore Phase test. Egon Pearsons test

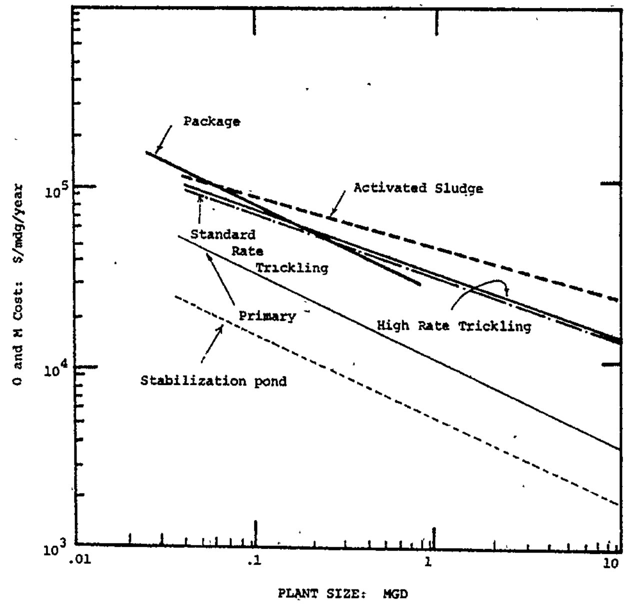

Figure 5. Operation and Maintenance Costs per Mgd at White River Lake, Texa

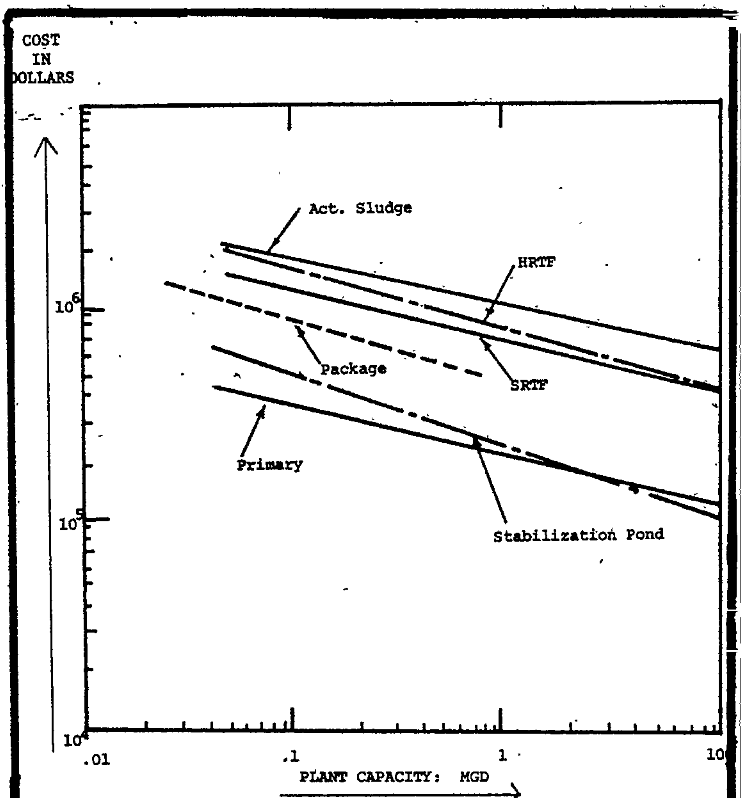

Figure 6. Construction cost per Mgd.

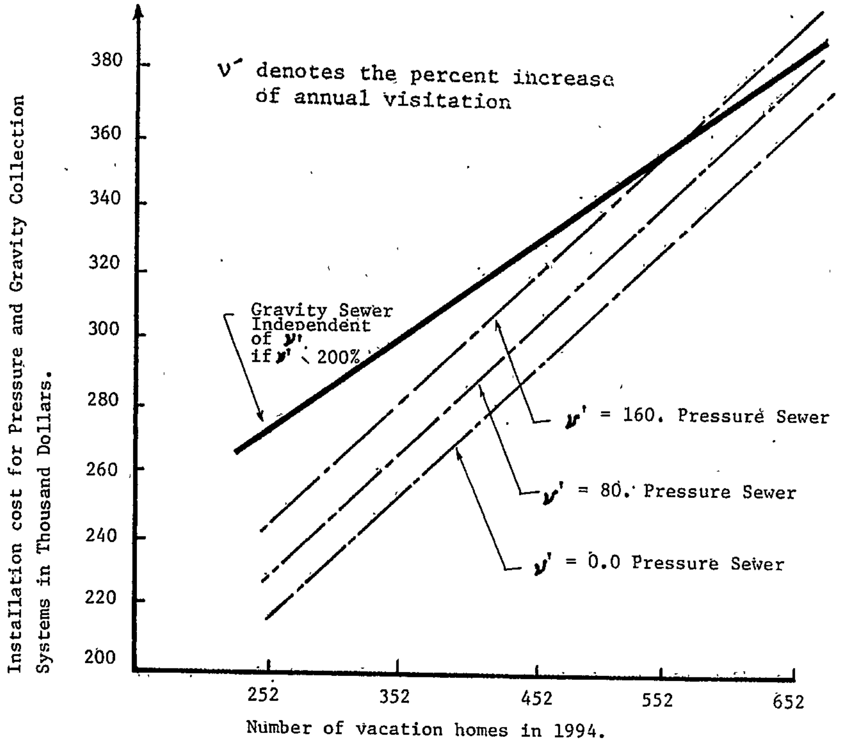

Figure 7. Relationships between the number of vacation homes projected by 1994 and installation costs for pressure collection and gravity flow collection systems with alternative increased rates of growth in daily visitation.

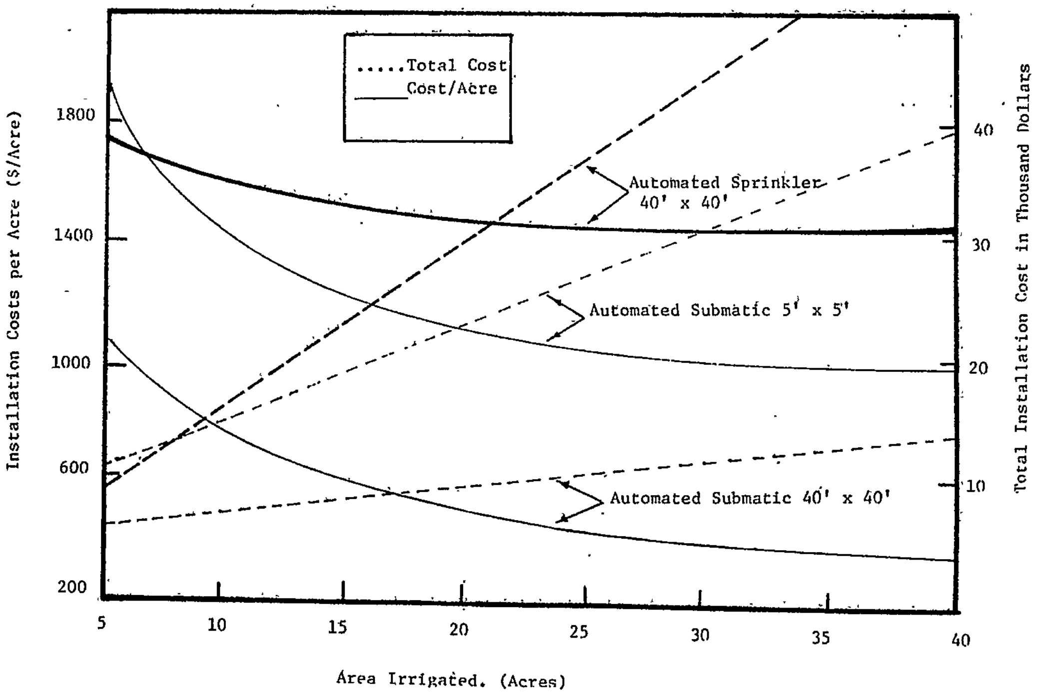

Figure 8 Installation costs of irrigation systems at White River Lake, Texas

and Geary's test for skewness and kurtosis provided the evidence of positive skewness of daily panevaporation values in these monthly periods. Gamma distribution functions were fitted to daily panevaporation records for each month. Phillip's FORTRAN subroutine (11) was used to generate gamma distributed daily panevaporation.

As indicated by Wald-Walfowitz run test, rainy days were assumed to be nonrandom. Conditional probability transition matrices for all monthly periods were estimated to explain the probability of a rainy day subject to prior daily rainfall conditions. Discrete probability distributions for the amount of daily rainfall were estimated from the past rainfall data. Once the simulation model generated a rainy day from the probability transition matrix, it used these discrete probability distributions for generating the amount of daily rainfall.

Four selected vegetation strategies, denoting four different plans regarding the number and varieties of shade trees and grassed areas to be grown, as evaluated in this study are defined in Table 1. The trunk diameters and canopy sizes of the trees, irrespective of of soils on which they are planted were assumed to increase at a constant rate each year. Mortality rates for all types of shade trees due to effluent irrigation were assumed to be 36, 24 and 12 percent in the first, second and third year after planting, respectively. All dead trees were assumed to be replaced by new trees of equivalent ages.

Experimental results of previous studies for orchards were used to estimate the consumptive water use of shade trees (7). The soil moisture reservoir for each tree was assumed to be cylindrical in shape with width being equal to the canopy diameter and length being equal to the depth of root structure. The depth of root structure for any tree was assumed to increase linearly from 36 inches to 84 inches in 20 years.

Irrigation efficiencies for sub-irrigation and sprinkler irrigation were assumed to be 1 and 0.7 respectively. Maximum and minimum permitted levels of irrigation for all trees were assumed to 100 percent and 60 percent of field capacities of soils respectively.

Table 1. Alternative Vegetation Strategies Evaluated in the Simulation Model

Vegetation Strategy Number	Soil Types	Number of Trees to be Grown a/			Acres of Grass Land to be irrigated
		Trees Type A	Trees Type B	Trees Type C	
Vegetation Strategy #1	Miles Fine Sandy Loam	1050	0	0	10 Acres in Campground 1
	Berda Loam	150	0	0	0
	Latom Polar Complex	1000	500	20	0
	Total	2200	500	20	10 Acres
Vegetation Strategy #2	Miles Fine Sandy Loam	1050	0	0	10 Acres in Campground 1
	Berda Loam	150	0	0	0
	Latom Polar Complex	0	500	20	0
	Total	1200	500	20	10 Acres
Vegetation Strategy #3	Miles Fine Sandy Loam	1050	0	0	0
	Berda Loam	150	0	0	0
	Latom Polar Complex	1000	500	0	0
	Total	2200	500	20	0
Vegetation Strategy #4	NO IRRIGATION				

a/ Approximate canopy sizes after 20 years of growth (irrigated) have been assumed to be as follows:
Tree Type A = 15 ft.canopy radius
Tree Type B = 10 ft. canopy radius
Tree Type C = 6 ft. canopy radius

RESULTS

Total system costs for alternative collection, treatment and irrigation methods for various vegetation strategies at different assumed rates of developments are illustrated in Figures 9, 10, 11, and 12. In all of these figures ν´ denotes the percent increase of annual number of visitors for fishing, camping, boating or other related purpose in the 20 years planning period. Number of vacation homes at the end of the planning period reflects the other component of additional development of recreational facilities at the site. In all of these figures PR stands for pressure collection; GR stands for gravity collection; PACK stands for package plant; PRIM stands for primary treatment plant; STAB stands for stabilization pond; HRTF stands for high rate trickling filter plant; SRTF stands for standard rate trickling filter plant; ACT stands for activated sludge plant; SUB stands for sub-irrigation; SPR stands for sprinkler irrigation and CAPACITY stands for the designed capacity of effluent storage. For example, a line marked as "PACK+STAB-PR-SUB" denotes the total system cost for a package plant and stabilization pond connected to pressurized sewage collection and sub-irrigation systems.

Figure 9 shows that for any rate of developments of recreational facilities at the site, a combination of pressure collection, package treatment plant, stabilization pond and sub-irrigation system

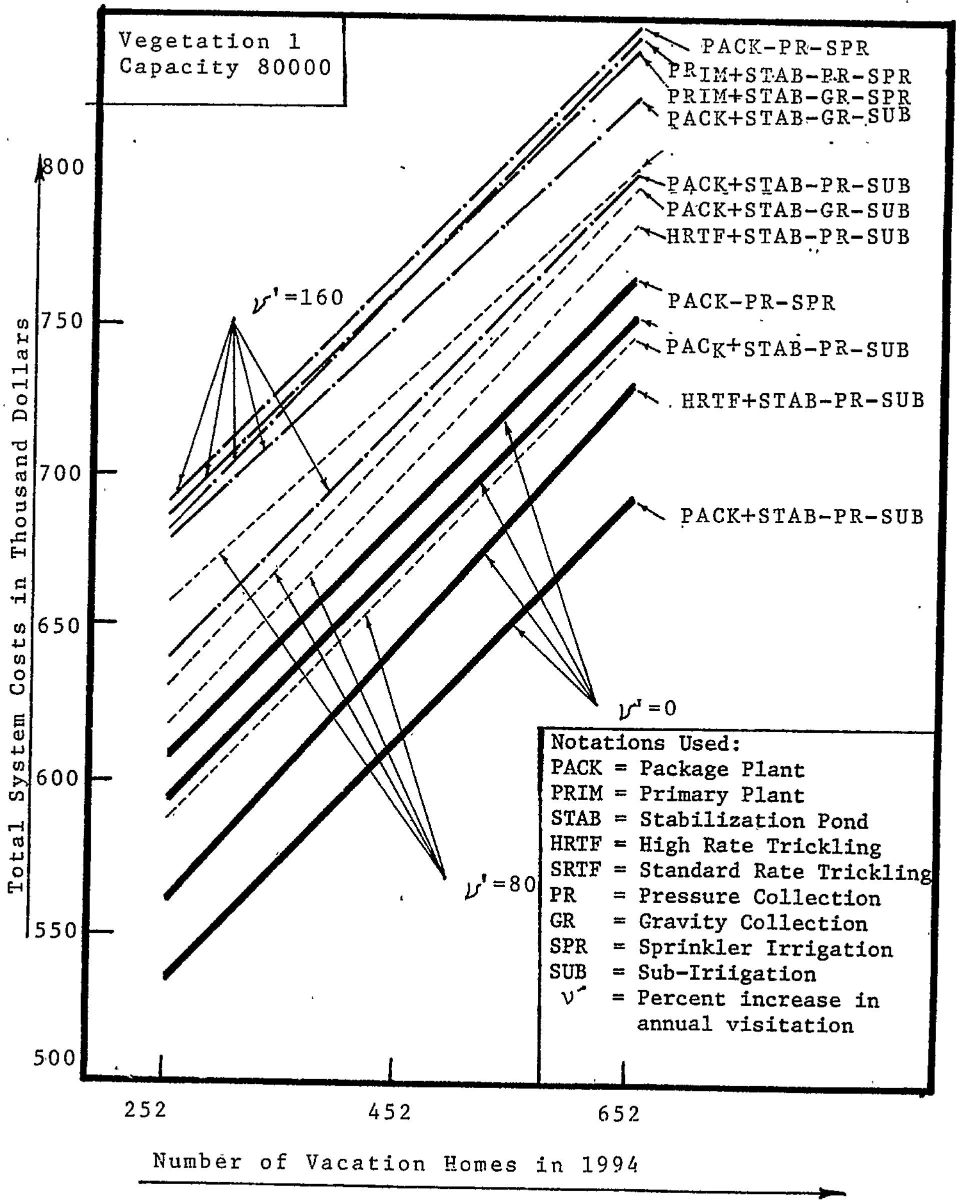

Figure 9. Total system cost for alternative collection, treatment and irrigation methods associated with vegetation strategy 1 at various assumed rates of developments at White River Lake, Texas.

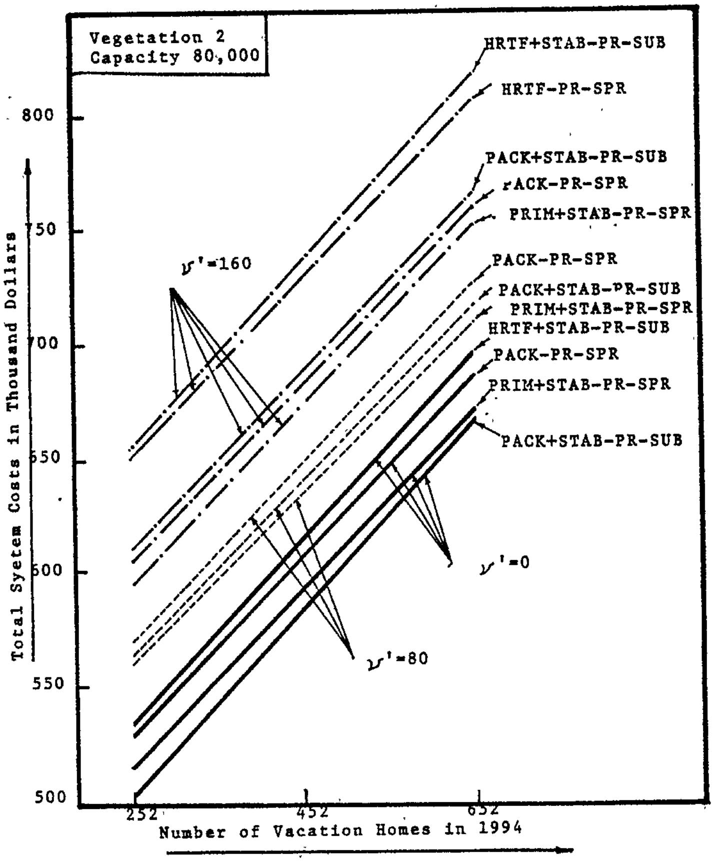

Figure 10. Total system cost for alternative collection, treatment and irrigation methods associated with vegetation strategy 2 at various rates of developments at White River Lake, Texas.

constitutes the least cost decision for vegetation strategy 1. A combination of pressure collection, high rate trickling filter plant, stabilization pond and sub-irrigation provides with the second lowest system cost. All combinations of collection methods and treatment plants entailed with sprinkler irrigation have considerably higher system cost.

Sub-irrigation method needs relatively more treatment of wastewater than sprinkler irrigation. Nevertheless, the economic advantage of sub-irrigation for vegetation strategy 1 exceeds the additional wastewater treatment cost.

It is noted that vegetation strategy 1 involves relatively large number of trees. As the number of trees to be grown increases, sub-irrigation method becomes relatively cheaper than sprinkler irrigation. This is clearly observed by comparing Figure 9 and Figure 10. Figure 10 shows the total system costs for various decision alternatives corresponding to vegetation strategy 2. Vegetation strategy 2 employes 1000 fewer number of trees than vegetation strategy 1. In case of vegetation strategy 2, although a package plant along with stabilization pond and sub-irrigation is the least cost decision at $\nu' = 0$, the sprinkler irrigation method becomes cheaper as ν' increases. At $\nu' = 80$, sub-irrigation no longer provides the least cost decision for vegetation strategy 2. The least cost decision is rather a combination of sprinkler irrigation associated to pressure collection, primary treatment and stabilization pond system. Since irrigation efficiency of sprinkler irrigation is less than that of sub-irrigation, relatively more supplementary irrigation water needs to be pumped from the lake at $\nu' = 0$. However, as ν' increases, the amount of wastewater increases. Hence, the amount of supplementary water to be pumped from the lake for sprinkler irrigstion is reduced. That is why, in case of vegetation strategy 2, sprinkler irrigation enters into the least cost decision as ν' increases from 0 percent to 80 percent.

Vegetation strategy 3 has same number of shade trees as vegetation strategy 1. However, it does not include lawn irrigation. Sub-irrigation is more expensive than sprinkler irrigation for irrigating grassed areas. Therefore, a relatively large

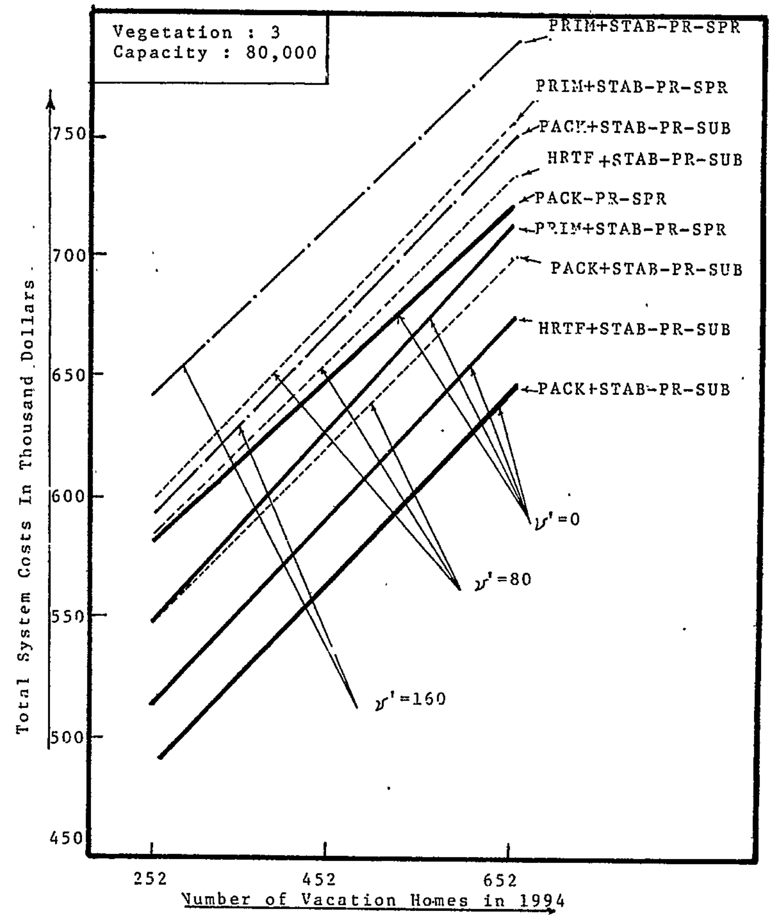

Figure 11. Total system costs for alternative collection, treatment and irrigation methods associated with vegetation strategy 3 at various assumed rates of developments at White River Lake, Texas.

number of trees along with no grassed area to be irrigated makes sub-irrigation even more favorable for vegetation strategy 3. The least cost decision for vegetation strategy 3 is same as that for vegetation strategy 1.

Figure 12 shows the systems costs for collection and treatment plants without entailing an irrigation system. Since, in this case, an irrigation system is not connected to the central sewage treatmant plant, a combination of primary plant, stabilization pond and pressure collection methods constitute the least cost decision for any rate of developments of vacation homes at the case study area.

CONCLUSION

The results of applying a system simulation model to a proposed sewer project that entailed several stages of decision-making regarding the method of collection, treatment and disposal among several irrigation alternatives indicate the usefulness and diversity of the approach.

Findings of this application to White River Lake, Texas indicates that a pressurized sewage collection method is more economical than conventional gravity flow collection method in a hilly terrain like White River Lake. It has been further validated that sub-irrigation method, although needs relatively more wastewater treatment and filtration than sprinkler irrigation, is of economic advantage for irrigating shade trees.

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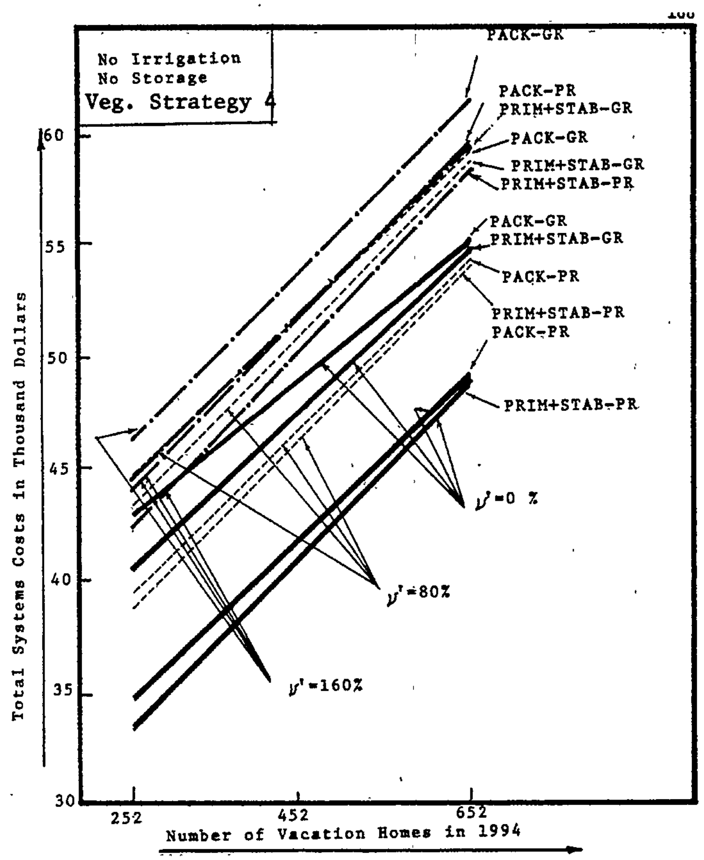

Figure 12. Total system costs for alternative collection, treatment and irrigation methods associated with vegetation strategy 4 at various assumed rates of developments at White River Lake.

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