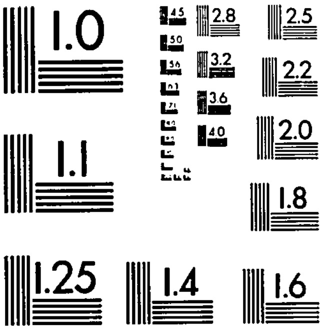

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# COMPUTER DESIGN OF ONSITE RESIDENTIAL LAGOONS FROM DEMOGRAPHIC, HYDRAULIC AND HYDROLOGIC VARIABLES

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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

# COMPUTER DESIGN OF ONSITE RESIDENTIAL LAGOONS FROM DEMOGRAPHIC, HYDRAULIC AND HYDROLOGIC VARIABLES

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

by

GARY DALE WOODRUFF

Norman, Oklahoma

1985

# COMPUTER DESIGN OF ONSITE RESIDENTIAL LAGOONS FROM DEMOGRAPHIC, HYDRAULIC AND HYDROLOGIC VARIABLES

A DISSERTATION

APPROVED FOR THE DEPARTMENTS OF

CIVIL ENGINEERING AND ENVIRONMENTAL SCIENCE AND SOCIOLOGY

By

Craig St. John

Jimmy F. Harp

Jerry G. Cleveland

# ACKNOWLEDGEMENTS

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when it was necessary to assume the less than exciting task of objectively reviewing and criticizing the results of a project for which he had not had the benefit of sharing in the design.

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# ABSTRACT

An investigative field study of onsite residential lagoon systems was conducted to identify important demographic and hydraulic variables affecting components of lagoon water balances. The goal was development of a computer design model for residential lagoons more sensitive to the sources of water balance variance. Dimensional and operating measurements were made of thirty-three onsite residential lagoon systems plus two additional commercial systems. Social and demographic data, as well as household water use habit data, were acquired by questionaire for the thirty-six households served by the lagoon systems. Neighborhood demographic change analysis, based upon selected census tracts in Tulsa, Oklahoma, was undertaken to identify predictable trends in household population and age characteristics. Predictive relationships developed from this analysis provided the basis for projecting long-term dwelling unit wastewater flow changes.

Lagoon water balance components included household wastewater influents, water surface incident precipitation, dike runoff precipitation, evaporation, and seepage. Computer design model relationships were developed from the most significant predictor variables. These include multiple regression prediction of wastewater influents from age-specific household population characteristics and seepage rates as they relate to vertical rise in lagoon depth above the

surrounding grade. Evaporation and incident precipitation water balance inputs are based upon probability analysis of local meteorological data. Dike precipitation runoff was also derived from probability analysis of local precipitation, modified by the inverse relationship between the percentage of precipitation runoff and average daily evaporation rates.

The computer design model is an interative type model, with one-month time steps, and attempts to optimize lagoon operating depth by accounting for water balance component changes based upon the results of the individual component predictive relationships. A twenty-five year water balance is computed for the design life of the facility and options for stressing the adequacy of the lagoon design are provided.

Seepage from the surveyed onsite residential lagoon systems was the water balance component of greatest importance in determining the facility design size. Occurring through the lagoon dikes in the area above the surrounding grade, seepage is great enough to render the model essentially insensitive to variations in other water balance components. As a result, the model predicts equivalent six-foot square minimum, default, bottom designs for all sizes of dwelling units up to twelve rooms.

# COMPUTER DESIGN OF ONSITE RESIDENTIAL LAGOONS FROM DEMOGRAPHIC, HYDRAULIC AND HYDROLOGIC VARIABLES

## CHAPTER I

## INTRODUCTION

Onsite total retention lagoons designed to serve individual single family residential dwellings are a relatively new wastewater treatment alternative which has gained increasing acceptance in Tulsa County and the state during the last decade. Evaporation ponds following septic tank/sand filter systems had been previously used for many years in the state. The introduction of the individual onsite lagoon system concept resulted largely from pressure to develop property for residential use in unsewered areas which exhibit heavy, clay soils with percolation rates too slow to allow the installation of conventional septic tank absorption field systems. Because of the relatively large land requirements needed for the installation of such lagoons, (Oklahoma State Department of Health regulations(1) require minimum lot sizes of 2.5 acres for the installation of these systems) their use has been limited largely to acreage subdivisions and rural areas.

## Problem Statement

Current Oklahoma State Department of Health design criteria(1) for onsite residential lagoon systems are based upon average household wastewater flows derived solely from the number of bedrooms in the dwelling unit to be served by the facility. Both field observations by personnel of the Environmental Protection Division of the Tulsa City-County Health Department and empirical evidence based upon regression analysis of census data and minimum residential water consumption data for the City of Tulsa(2), suggest that the average household wastewater production figures utilized by the state do not adequately reflect variations in wastewater flow from dwelling units under actual field conditions. The result is often overdesign or underdesign of these systems. Because of inefficient design, many systems require more land area for installation than necessary, resulting in higher construction costs and a tendency to operate below their optimum design depth resulting in problems with rooted aquatic vegetation and the associated problem of nuisance insect breeding. A less frequent problem is overflow from those systems which are underdesigned utilizing this methodology.

## Research Objective

The primary objective of this research was to develop a more accurate computer design model for onsite residential lagoon systems with improved sensitivity to the sources of variance affecting lagoon water balances. The study was premised on the assumption that much of the variance in lagoon water balance equation components could be explained by identifying causative relationships between wastewater influent flows and water distribution systems, housing, and household occupant characteristics as well as through better accounting for variances in seepage, precipitation and evapotranspiration.

The proposed model would be an iterative type computer model, designed to compute monthly water balances for the expected design life of the facility, optimizing operating depth at a preselected level while controlling for both unacceptably high and low operating depths which could result in overflow or, conversely, the establishment of nuisance vegetation. Variations in dwelling unit wastewater flow rates were examined from the standpoint of their predictability from physical household characteristics, water pressure variables and demographic and social characteristics of the occupants.

Household wastewater flow rates are subject to both short-term and long-term temporal variations. Short-term fluctuations in household flows on hourly, daily, or even weekly bases, are of little significance in the design of residential lagoon facilities since such fluctuations are dampened by the facilities' storage capacities. Long-term fluctuations in wastewater flow rates, resulting from changes in household demographic or social characteristics brought about by changes such as maturation of children and occupant turnover due to sale or renting of the dwelling unit, have the potential of significantly impacting wastewater flow rates and required detailed examination. Variances in precipitation and evapotranspiration have both seasonal and annual manifestations, while fluctuations in both have the potential for significantly affecting residential lagoon design and operation. Precipitation impacts required examination from the standpoints of both precipitation incident to the water surface and precipitation excess (runoff) from the surrounding dike. Precipitation and evaporation variables were analyzed from a probablistic standpoint in which their impacts were assessed according to predictable return periods and the inverse relationship between the two was examined for predictability.

Wastewater seepage from lagoons required evaluation to determine both the magnitude of the impact of this component on the water balance equation and the extent of it's possible predictable relationship to physical characteristics of soils and lagoon design, if any. Seepage was determined as a residual of the water balance equation for the facilities after other equation components were quantified as accurately as possible.

The key consideration in the selection of input variables to support the computer model was that these variables be easily obtainable at the time the system is designed and either not change, or be subject to predictable change, during the design life of the facility. This requirement limited the model input variables to the relatively unchangeable physical characteristics of the dwelling unit and, possibly, of the project site, and made it necessary to attempt to account for the impact of long-term temporal changes in the social and demographic characteristics of the occupying households by means of predictive relationships with physical variables.

## Research Scope

The scope of this research involved the collection and analysis of questionaire and field measurement data on the participating households and their corresponding lagoons, as well as probability and statistical analysis of historical rainfall, evaporation and census data. The primary components of the study included the following:

1. All lagoon facilities designed or approved by the Environmental Protection Division of the Tulsa City-County Health Department since 1975 were identified.

2. A questionaire was developed and distributed to all identified lagoon owners in the Tulsa Metropolitan Area soliciting their participation in the study. The questionaire delineated social and physical characteristics of the dwelling units and households served by the facilities.

3. Field visits were made to each participating lagoon site at approximately one-month intervals to aquire static water pressure levels, water consumption data, lagoon operating level measurements, and detailed physical measurements and characteristics of the facility itself.

4. Precipitation data were acquired through a volunteer network and the City of Tulsa recording rain gauge network during the course of the study.

5. Tabulation and statistical analysis of the household and lagoon data were completed, including water balance calculations for each system with subsequent determination of seepage rates.

6. Census tract data for 1960, 1970 and 1980 for predominantly single family census tracts were acquired and analyzed for the identification of long-term trends in social and neighborhood change which might reflect similar trends in wastewater flow rates from individual households.

7. A supplemental study of lagoon dike precipitation runoff from two additional facilities was completed to better establish runoff rates into the lagoons.

8. A computer design model for onsite residential lagoon systems was developed based upon the predictive relationships and probability distributions resulting from analyses of the questionaire, census, lagoon, precipitation and evaporation data.

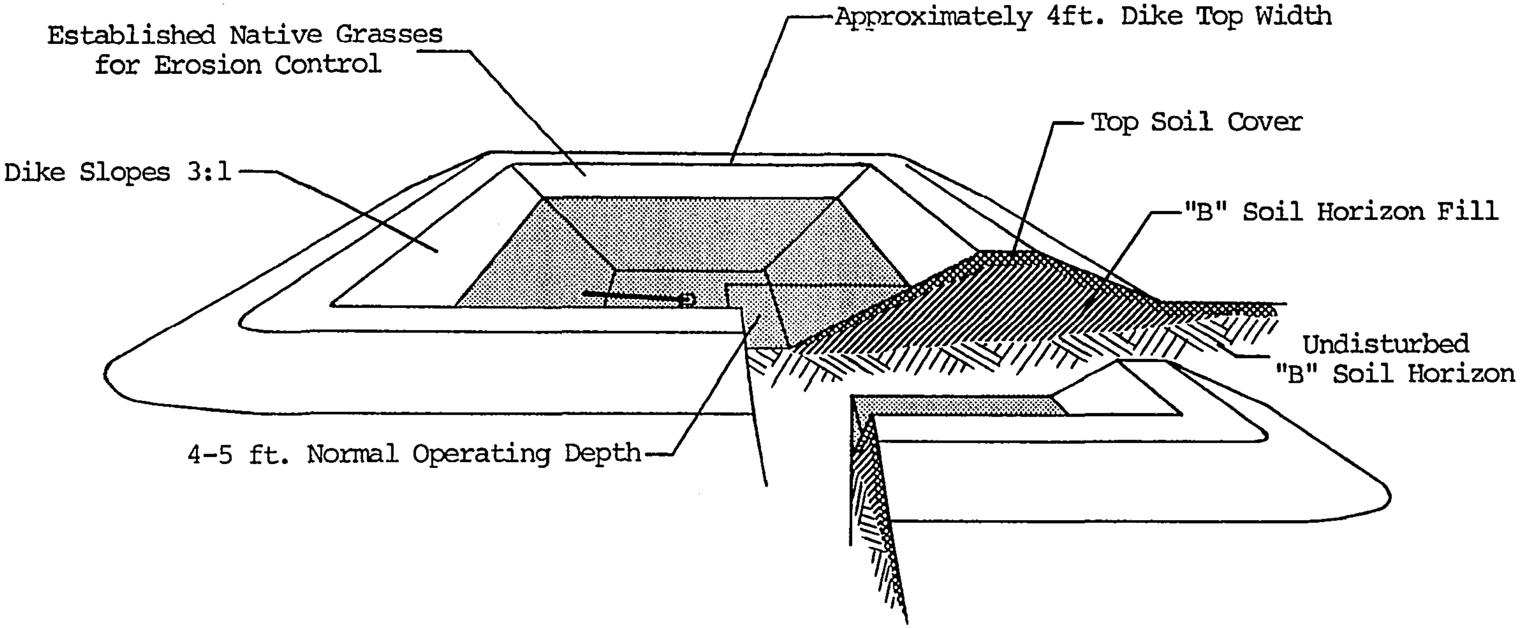
# CHAPTER II

# BACKGROUND

## General Design Considerations

Onsite residential lagoon systems are total retention in design, i.e., designed for no wastewater discharge. Household wastewater is usually routed through a conventional septic tank before being discharged to the lagoon for subsequent treatment and evaporation. Figure 2.1 shows a typical onsite residential lagoon system. Annual rainfall and evaporation rates are taken into account in sizing lagoons to insure that net evaporation is sufficient to evaporate the wastewater flow entering the lagoon from the residence. The EPA design manual, Onsite Wastewater Treatment and Disposal Systems(3) lists the major climatic factors affecting the performance of lagoon systems as sunlight, wind circulation, humidity, and the resulting net evaporation potential. The manual also notes that lagoon size and soil permeability are inversely proportional for evaporation/infiltration lagoons. However, these systems are not allowed in Oklahoma since state design standards require the dikes and bottoms of lagoons to be of impervious, throughly compacted material(1). For evaporation lagoons, the EPA manual notes that salt accumulation over time will result in decreased evaporation rates.

Figure 2.1 Typical Onsite Residential Lagoon System



Individual wastewater retention lagoons are normally constructed in a square or rectangular configuration with side slopes between 3:1 and 2:1. In order to maintain proper waste mixing and aeration of the lagoon surface, it is necessary to trim vegetation on the dikes during the growing season. Discharge of wastewater near the center of the lagoon, as required by Oklahoma State Standards, improves mixing and solids distribution and minimizes odor. Slopes must be shallow enough to allow mowing to be carried out and yet sufficiently steep, on the inside slope, to minimize rooted aquatic vegetation growth from occurring in the lagoons. On the other hand, depending upon soil type and stability, erosion must be prevented from destroying the inside of the dikes resulting in undesirable accumulations of silt in the lagoon bottoms. Solids removal is periodically required from evaporation lagoons although little data are available to indicate the frequency of removal required for these systems(3). Since construction of individual wastewater treatment lagoons is normally needed in areas where soil percolation rates are insufficient to support conventional septic tank and absorption field disposal systems, the underlying soils are normally of high clay content and provide a natural barrier to seepage from lagoons.

The operating water levels of onsite total retention lagoons are subject to the dynamics of gains from wastewater influents, precipitation, and groundwater inflow as well as water losses from evapotranspiration from wetted surfaces and vegetation on the surrounding dike, and seepage into the underlying soils and bedrock formations. In order to determine the proper design size of a total retention facility, each of these factors must be taken into account. In so doing, the minimum and maximum operating fluctuations of the water surface of the facility can be determined as they change seasonally.

Precipitation and evaporation are subject to predictable (at least from a probabilistic standpoint) seasonal changes. Influent flows are often determined on a per capita basis from averages reported in the literature with safety factors incorporated to account for unusual variances. In Oklahoma, design standards are based upon anticipated flows relating to the number of bedrooms contained in the dwelling which presumably reflects the average number of individuals who would be expected to reside there. From a long-term, design life point of view, however, the influent contribution to a facility can be expected to change with changes in the size and characteristics of the family inhabiting the dwelling unit as it is sold or rented to successive owners. The design component based upon influent flows should remain flexible, therefore, to accomodate influent changes throughout the life of the facility and the dwelling unit it serves.

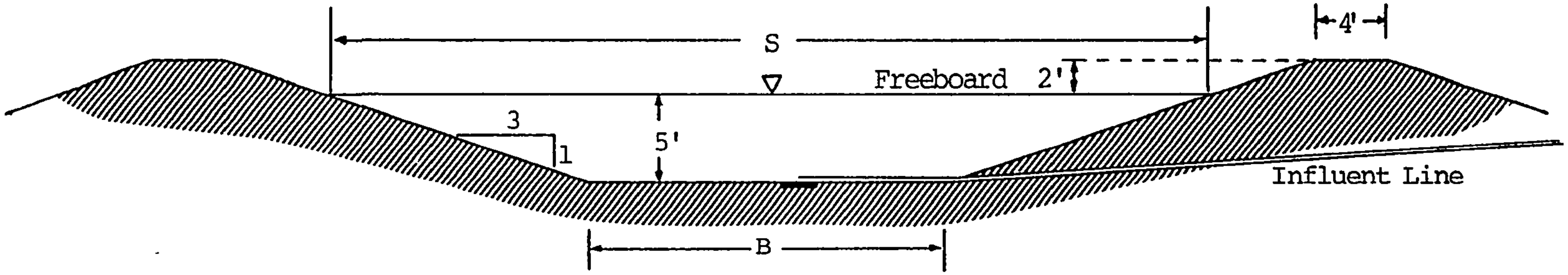
Although transpiration and groundwater inflow are not normally considered to be important factors in the overall water balance during the design of these facilities, it is reasonable to assume these factors do contribute to overall system dynamics during some seasons of the year. For example, during the growing season transpiration of water from grasses growing on the surrounding dike may be significant as may evaporation of water from soil surfaces dampened by osmotic action near the water surface. During winter months many of the soils in which individual onsite lagoons are constructed may periodically exhibit "perched" water tables. Depending upon the operating levels of the individual facilities and the elevations of the "perched" water tables, hydrostatic pressure of the groundwater may be sufficient to result in groundwater inflow into the lagoons.

## Current Design Criteria and Standards

Current Oklahoma State Department of Health design criteria for onsite residential lagoons are based upon singular, specific flow rates for two-, three-, and four-bedroom dwelling units(1). Typical lagoon designs applicable to Tulsa County, Oklahoma, based upon the current state criteria, are shown in Figure 2.2. The designs in this figure are based on square lagoons with five-foot operating depths. State regulations allow for alternative designs of rectangular dimensions. The design criteria specify a two-foot freeboard from the water surface to the top of the surrounding dike to allow for additional storage during unusual climatic conditions in which net evaporation is negative.

Early recommendations for design of individual lagoons in areas unsuitable for conventional subsurface wastewater disposal systems were developed as a cooperative effort by personnel of the U.S. Department of Agriculture, the Oklahoma State Department of Health and the Oklahoma State University Cooperative Extension Service(4). The design was based upon a four-foot overall depth with one foot of minimum storage and an overlying one-foot additional operating depth within which the lagoon surface would fluctuate during periods of varying precipitation and evaporation. Design sizes were based upon bottom area recommendations as they related to influent flows of 150, 200 or 250 gpd within seven separate zones across the state. The zones formed roughly vertical bands

Figure 2.2 Design Criteria for Onsite Residential Lagoons Applicable to Eastern Tulsa County, Oklahoma(1)



A = Surface Area (ac.) = $\frac{Q}{(E-P) \times 27,200}$

Q = Annual Household Wastewater Flow (gal/yr)

E = Avg. Annual Pan Evap. (in.) = 75 in.

P = Avg. Annual Precip. (in.) = 38 in.

S = Length of one side at water level (ft.)

= $(A \times 43,560 \text{ ft}^2/\text{ac})^{1/2}$

B = Length of one side of bottom (ft.)

= S-30 ft.

| No. Bedrooms | Design Waste Flow (gal) Yearly (Q) | Daily | Monthly | A (ac) | S (ft) | B (ft) |
|---|---|---|---|---|---|---|
| 2 | 72,000 | 197 | 6,000 | .072 | 56 | 26 |
| 3 | 96,000 | 263 | 8,000 | .095 | 64 | 34 |
| 4 | 120,000 | 329 | 10,000 | .119 | 72 | 42 |

one to two counties in width. The recommendations are not greatly dissimilar to those contained in current state criteria which, by law, govern lagoon construction. The lagoon sizes recommended in the committee publication are now known to be excessively large due to unaccounted for seepage and evapotranspiration(5).

State construction standards for onsite residential lagoons restrict their location with respect to distances from adjacent wells, water supplies, dwellings and property lines, and specify discharge into the center of the lagoon cell. Standards also require fencing equivalent to a five-foot, six-strand barbed wire fence, sign posting to indicate the nature of the facility, seeding or sodding for erosion control, a maximum 3:1 side slope and compaction of dikes and bottoms. Appendix A contains excerpts from Oklahoma State Deaprtment of Health Bulletin No. 600(1) which details the specific rules and regulations governing the design and construction of these facilities.

Total retention lagoons with five-foot operating depths are facultative lagoons in most cases. That is, organic waste stabilization occurs under aerobic conditions near the surface of the pond with a gradient to anaerobic decomposition near the bottom. Oxygen for waste stabilization in the aerobic zone is provided by the photosynthetic action of algae suspended in water and through oxygen interchange at the air/water interface, supported by wind action at the pond surface. It is desirable, from the standpoint of reducing odor problems from these facilities, to maintain aerobic conditions in the upper portions of the lagoon. Facultative ponds are the most common type of domestic waste stabilization ponds in the United States(6).

The five-day biochemical oxygen demand ($BOD_5$) loading rate for total retention lagoons is recommended by Middlebrook, et al.(6) to be equivalent to that of flow-through facultative ponds which, within the average winter temperature range of 32 degrees to 60 degrees F, applicable to the Tulsa area, is 20 to 40 lbs/ac/day. EPA's design manual Municipal Wastewater Stabilization Ponds(7) recommends this same rate of loading, noting that facultative lagoons with light loads may remain aerobic throughout their entire depths. The EPA design manual for onsite systems, previously discussed,(3) addresses the design and construction of evaporation and evaporation/infiltration lagoons for individual residential applications. It recommends that these systems be designed based upon $BOD_5$ loadings appropriate for odor control,suggesting that the loading range should be between 11 and 35 lbs/ac/day of $BOD_5$ as recommended by several literature sources. The manual notes that, while thousands of such individual total retention lagoons systems are currently in use in the United States, performance data are very limited. The design section of that publication is based upon current practice in the field and contains the disclaimer that no assurances are given that such practices are optimal. Routing of the raw wastewater through a septic tank for pretreatment is recommended, especially when a garbage disposer discharges to the system. In Oklahoma, pretreatment via a septic tank is required(1). Such pretreatment removes objectionable floating and suspended solids from the wastewater and reduces overall suspended solids levels discharged to the evaporation lagoon.

In eastern Oklahoma, due to the relatively low net evaporation rate, the limiting design criteria for residential lagoon systems is normally the hydraulic loading rate rather than the surface loading rate. In drier climates, where evaporation greatly exceeds rainfall, surface loading can be the controlling factor for proper design. For the average three-bedroom dwelling, with an assumed occupant population of 3.5 individuals, under current state designs standards applicable to Tulsa County, Oklahoma, a lagoon system designed for a hydraulic load of 8,000 gallons per month would be receiving a surface $BOD_5$ load of only 6.3 lbs/ac/day, (actually, only 4.4 lbs/ac/day, assuming a thirty percent septic tank BOD removal pretreatment efficiency) far below the range of recommended loadings previously discussed. Under these light loading conditions, many Tulsa area residential total retention systems may be operating as aerobic facilities throughout much of the year.

Individual wastewater treatment systems designed under Oklahoma standards are based upon average annual rates of influent wastewater flow, evaporation, and rainfall. Seepage from the facilities, as such, is not separately taken into consideration. Design is based upon maintaining an average five-foot liquid depth with sufficient surface area to evaporate influent flows by taking advantage of the net evaporation potential. Incorporation of a two-foot freeboard, above the five-foot operating depth to the top of the surrounding dikes, is required to provide sufficient excess capacity to accomodate unusual weather conditions during which excessive rainfall occurs and evaporation rates are below normal. Under actual operating conditions, lagoon levels are lowest during late summer when evaporation rates are very high and rainfall is sparse. During late winter, when evaporation rates are low and spring rainfall is beginning to increase, lagoon levels would be expected to be at their highest. Actual operating levels of lagoons during all months of the year can be estimated by developing system water balances accounting for influent flows, precipitation into the lagoons and evaporation from the facilities on a month to month basis.

Under normal conditions, lagoon construction begins with the removal and stockpiling of subsoil from the lagoon site. B-Horizon soils are normally used for dike construction, taking care to assure that a good interface between the dike and the native soil is developed to reduce seepage which would be likely to occur at this interface. Surface water runoff into the facilities, other than that falling directly upon the insides of dikes, is excluded. On sloping lots this is accomplished by providing intercepting diversion swales on the upslope sides of the facilities.

Following the building and compaction of the dikes, topsoil is spread over the newly created dikes to provide soils suitable for growth of stabilizing vegetation. When "start-up" of a newly constructed lagoon system is properly carried out, the lagoon is filled from a fresh water source to a depth of approximately two feet. The maintenance of a two-foot minimum wastewater depth in the lagoons is important to circumvent the growth of rooted vegetation which would reduce wave action and subsequent oxygen interchange, as well as tend to promote the breeding of nuisance insects in the lagoons.

# CHAPTER III

# MATERIALS AND METHODS

## Selection of Participating Systems

Selection of the individual lagoon systems studied was initiated by identifying all onsite residential lagoons approved and constructed since 1975, as determined from files of the Environmental Protection Division of the Tulsa City-County Health Department. Ninety-one such systems were identified. During the conduction of the field surveys, several additional lagoon systems were encountered for which official records had not been located.

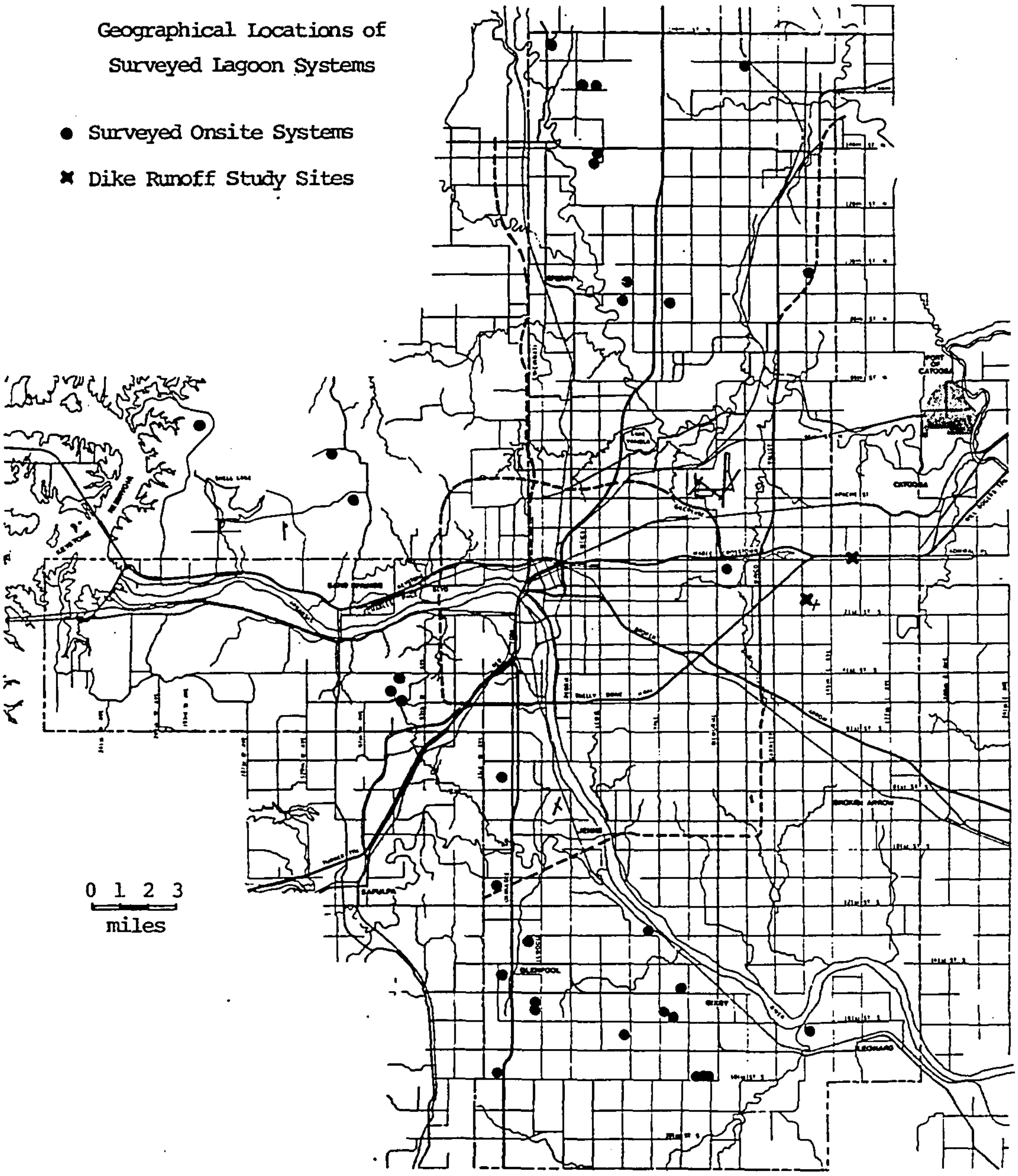
Due to the limited number of lagoon systems in the Tulsa area available for study, rather then rely upon random selection, as many identified systems as possible were contacted for inclusion in the study in the hope of increasing the study sample size. The overall response to requests for voluntary participation was approximately thirty-six percent or thirty-one of the ninety-one identified systems. Although this number was less than desired, it did provide an adequate sample for examination of most of the social, physical and operational data analyzed. Due to the lack of randomized sampling, however, the possibility for statistical bias due to the voluntary nature of the selection process exists. The important consideration, with respect to such self-selection bias, is the degree to which any such bias introduced would be reflected in altered wastewater flow characteristics from the participating families. The most likely area of bias, as reflected by wastewater flow characteristics, would be that relating to the social strata and/or age characteristics of the participants.

Examination of the results of the household survey data, which are presented in Chapter IV, do not suggest a significant degree of bias is likely in view of the broad ranges and distributions of dwelling sizes, types, values, inhabitant ages, etc. of the dwellings and families which volunteered to participate in the study. In addition, examination of the general lagoon data reflects a high percentage of systems which were relatively poorly maintained with respect to state standards, making it apparent that all of the participating systems were not "model" lagoons. Distribution of the participating systems was widespread with systems located in unsewered areas characterized by soils with failing percolation rates throughout the Tulsa metropolitan area as may be noted in Figure 3.1.

The participating systems included thirty-three onsite lagoons serving a total of thirty-six dwelling units. Three of the lagoon systems served two seperate dwelling units. One additional system, which had been volunteered for participation early in the survey, was lost from the study after the dwelling unit was destroyed by a rare December tornado during Christmas week of 1982. Several lagoon owners responded to the request for participation by indicating they did not wish to be included for various reasons, some indicating they no longer

Figure 3.1

Geographical Locations of
Surveyed Lagoon Systems



● Surveyed Onsite Systems

✖ Dike Runoff Study Sites

had lagoon systems or never did have such systems.

### Household Survey Procedures

A questionaire was developed to be completed by the families occupying the participating dwelling units. Questions were designed to obtain household physical and social characteristics which might be related to the variability of household wastewater flow characteristics. Information requested included the type of dwelling, square footage, original cost, source of water, types and numbers of rooms, frequency of use of garbage disposers, automatic dishwashers and clothes washers, the approximate number of baths and showers taken per week and the number and ages of all persons residing in the dwelling unit. A copy of the questionaire is contained in Appendix B.

It was necessary to establish the current names and mailing addresses of the owners of each of the ninety-one systems located in the Tulsa metropolitan area since many had either changed since the initial construction of the systems, or mailing addresses were unassigned when the systems were installed. This was accomplished for Tulsa County Systems by matching legal descriptions on file for each system with current tax roll records of the County Assessor's Office.

On December 15, 1982, questionaires with postage free return envelopes were mailed to all of the lagoon owners for which current addresses could be determined. A cover letter was included describing the research project, discussing the importance of the participation in the program, and assuring confidentiality of the information provided. A copy of the letter is contained in Appendix B. The initial mailing of the questionaires resulted in approximately fifteen volunteering respondents. This response was considerably less than anticipated, possibly because of the intervening Christmas holidays. Immediately following Christmas, as many as possible of the system owners were contacted by telephone and reminder letters with duplicate questionaires were mailed during the first week of January to solicit additional participants. During the early part of January, 1983, additional participants were gradually acquired, many after the first site inspections were begun on January 6, 1983. By the end of January, thirty-one systems had been included in the project with the final two systems incorporated into the study shortly thereafter.

## Lagoon Survey Procedures

With the exception of one lagoon system enrolled late in the study, field inspections of each lagoon were made on three separate occasions at approximately one month intervals, depending upon the number of days the system was included. The longest number of days any system was under observation was seventy, with the shortest number of days being forty-five (thirty-one days for the late respondent). Most of the systems were studied for between sixty-five and seventy days.

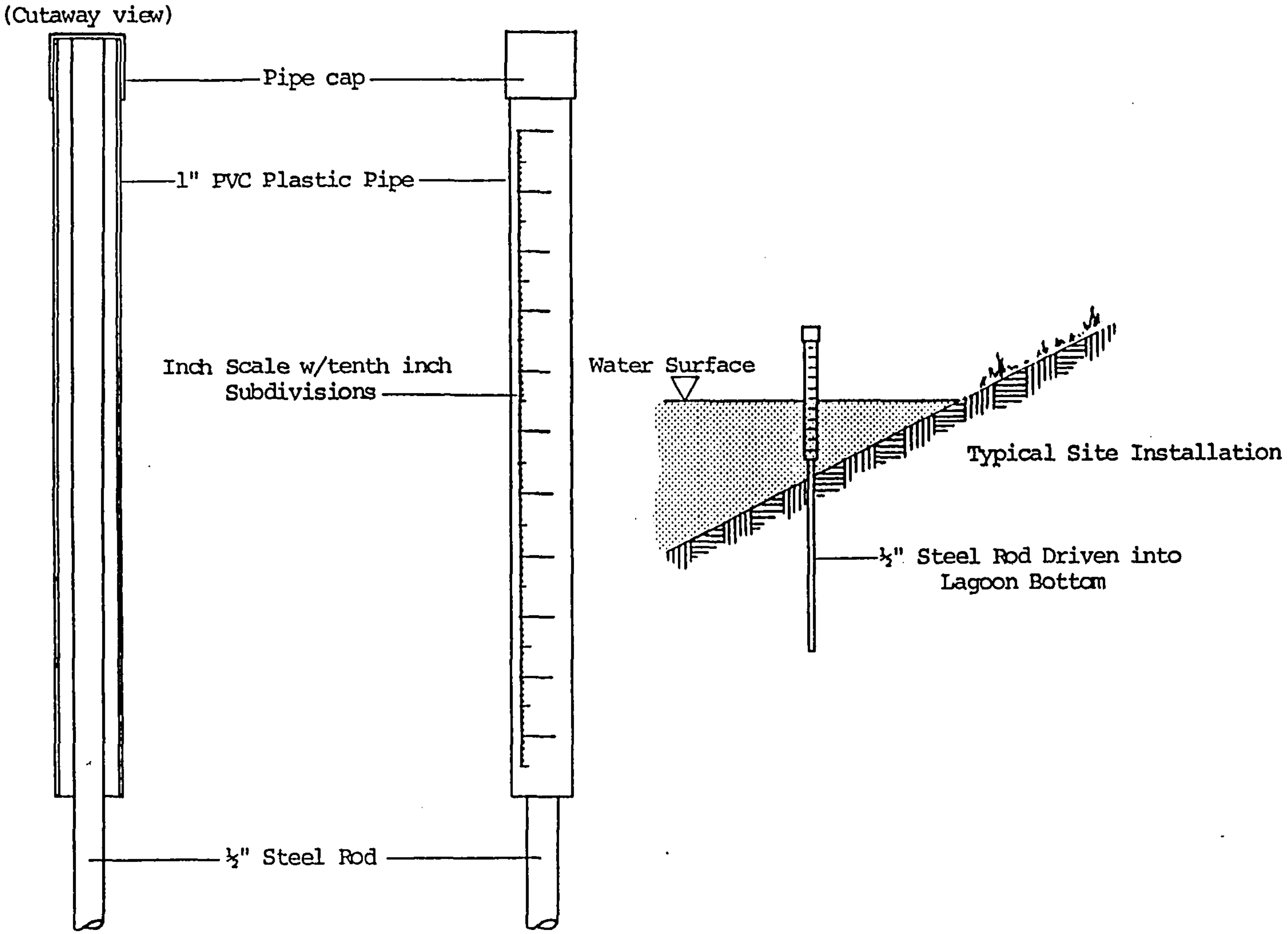
Field data measurements of the lagoon systems were recorded on a field data sheet prepared prior to the initiation of the study. A reproduction of the data sheet is contained in Appendix B. The field data sheet included entries relating to the lagoon's existing operating level and maintenance condition, along with water surface elevation. These measurements were taken at the initial visit and at the end of the first and second months return visits. As each system was visited, static water pressure was measured at an outside hydrant of each dwelling unit to provide data which could be later used to determine the significance of static system water pressure in explaining a portion of wastewater flow variance among dwelling units. Water meter readings were also taken at each dwelling unit in order that water consumption and, consequently, influent wastewater flows into the systems could be determined for use in the water balances for each system.

The water surface dimensions of each lagoon were measured in both length and width as well as, in some cases, depending upon the lagoon configuration, diagonally. Onsite drawings of each facility were made and, where necessary, additional measurements made to determine curvatures of unusually rounded corners. From these drawings the surface area of each lagoon at the initial visit was planimetered and surface area at subsequent visits determined. The potential precipitation runoff area of the surrounding dikes was determined in a manner similar to surface area by utilizing length, width, and diagonal measurements of the tops of the lagoon dikes at the approximate locations of the highest points dividing flow into the lagoon from that toward the outsides of the dikes. Incident precipitation to the water surface could thus be separated from dike precipitation.

The water surface levels of the lagoons were measured at each site visit. Since a primary objective of the study was to establish a water balance for each system and, particularly, to establish seepage rates from the facilities, it was necessary only to determine relative changes in water level during the course of the study. All other variables in the water balance equation, except seepage (e.g., influent flows, incident precipitation, precipitation runoff and evaporation), could be directly measured or estimated with reasonable accuracy. The method of determining water level fluctuations of the lagoon systems during the study involved driving a stake of half-inch steel reinforcing bar or sucker rod, approximately three feet in length, into the lagoon bottom. The stake was positioned approximately two feet from the water's edge at a depth which left about seven inches of stake exposed above the water surface. It was driven deep enough into the lagoon bottom to circumvent movement in the event the lagoon froze during the course of the study (an eventuality which did not occur to any significant degree). The measuring device itself was fashioned from a fourteen-inch piece of white PVC plastic water pipe with one end capped. An inch scale, divided into tenths, was scribed along the side of this pipe. When the pipe was inverted and placed over the steel stake in the lagoon, a notation could be made of the inches of submersion of the pipe (See figure 3.2). In this manner, the relative change in lagoon water level could be determined from one site visit to the next. It was necessary to shield the measuring device from wave action during unusually windy conditions. Changes in water level could easily be determined within one-tenth inch accuracy in this manner.

An unusually intense storm system with heavy rainfall near the end of January, 1983, was responsible for complete submersion of the measuring rod at some locations. This necessitated the fabrication of a four-inch dowel plug which could be inserted into the PVC pipe to raise the level of the scale above the water surface in order that

Figure 3.2 Lagoon Water Surface Elevation Measuring Device



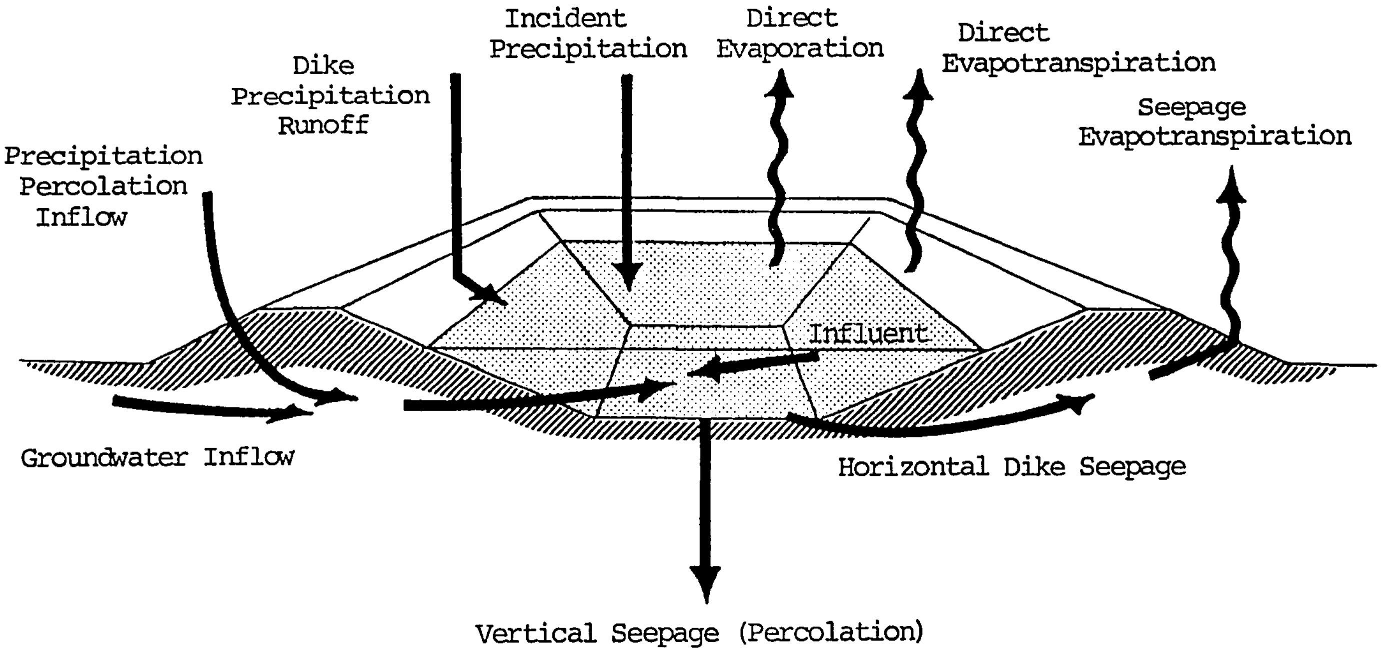
measurements could be made. The four-inch adjustment in the measuring scale was taken into account when water level data were recorded on the field sheets.

## Water Balance Data Acquistion

The computation of individual lagoon water balances necessary for determining seepage losses from the facilities, required the accurate determination of water quantities associated with each of the water balance equation components. Lagoons are subject to water gain and loss through several potential mechanisms, the relative importance of each may vary significantly between facilities. Figure 3.3 shows the primary potential influences on lagoon water level fluctuations, the more important of which include: 1)influent wastewater flows, 2)incident precipitation to the lagoon water surface, 3)dike precipitation runoff, 4) direct evaporation from the water surface, and 5) seepage loss.

Other sources of water gain to lagoon systems might include inflow of groundwater from "perched" water tables in certain soils and inflow of precipitation percolating into lagoon dikes. The extent of such inflows would be governed by the hydrostatic pressure differentials between the ground water and that in the lagoon itself and would be significantly influenced by local topography. Additional water loss mechanisms affecting total retention lagoons include evapotranspiration from wetted soil surfaces and vegetation on the interior of lagoon dikes near the water surface, and evapotranspiration from wetted soil surfaces and vegetation on the exterior of lagoon dikes resulting from seepage through the dikes.

Figure 3.3 Primary Total Retention Lagoon Water Balance Influences



Determination of water gains and losses resulting from groundwater inflow, precipitation percolation, and evapotranspiration cannot be easily determined individually. Therefore, data acquisition for water balance calculations emphasized accurate determination of incident and runoff precipitation quantities, evaporation, and influent flows. By quantifying changes in lagoon operating level and, consequently, changes in lagoon wastewater volume, the resulting loss or gain to each system could be determined as a residual. For purposes of simplifying inputs to the lagoon design model, the loss or gain residual is treated as simply seepage loss since this is the major component of the residual for most systems relative to inflows and evapotranspiration. For purposes of technical accuracy, however, it is important to recognize the multiple variables included in the seepage component as utilized in this study. Calculation of lagoon seepage loss, as the water balance residual for each system, is determined by the following equation:

$$L = I + P_i + P_r - E - S$$

or, rearranging:

$$S = I + P_i + P_r - E - L$$

Where:

$S$ = Lagoon seepage loss

$I$ = Dwelling unit wastewater influent

$P_i$ = Incident precipitation

$P_r$ = Dike runoff precipitation

$E$ = Water surface evaporation

$L$ = Change in lagoon volume

## Household Wastewater Influents

The close relationship between residential water consumption and wastewater flow rates during winter months, when outside water use is limited, is widely accepted. Summer increases in residential water consumption are attributed to lawn sprinkling and other outdoor uses. As a result, the practice of assuming that winter water demands are equivalent to year-round residential wastewater flows is generally accepted in the engineering field. According to Hanke and Davis(8) this assumption has been imperically verified by Howe and Lindaweaver, Jr.(9).

Local confirmation of minimum water consumption occurring during winter months was made in analyses by the Tulsa City-County Health Department of water consumption by the communities of Collinsville, Claremore, Owasso, Sapulpa, Pawhuska, Drumright, Broken Arrow, Bixby, and Tulsa, Oklahoma for the years 1969 through 1975(10). Results of this study, graphically presented in Figure 3.4, shows the historical months of low water consumption for the Tulsa area to be January through March. For this reason, it was appropriate to conduct this research during that period in order that direct readings of residential water consumption could be made and assumed to be equivalent to wastewater flows. Discussions with dwelling unit residents and site observations indicating any outdoor water use or household activities which would result in abnormal increases or decreases in water consumption during the period of the study were noted and appropriate adjustments made. For example, watering of livestock from the household supply or extended

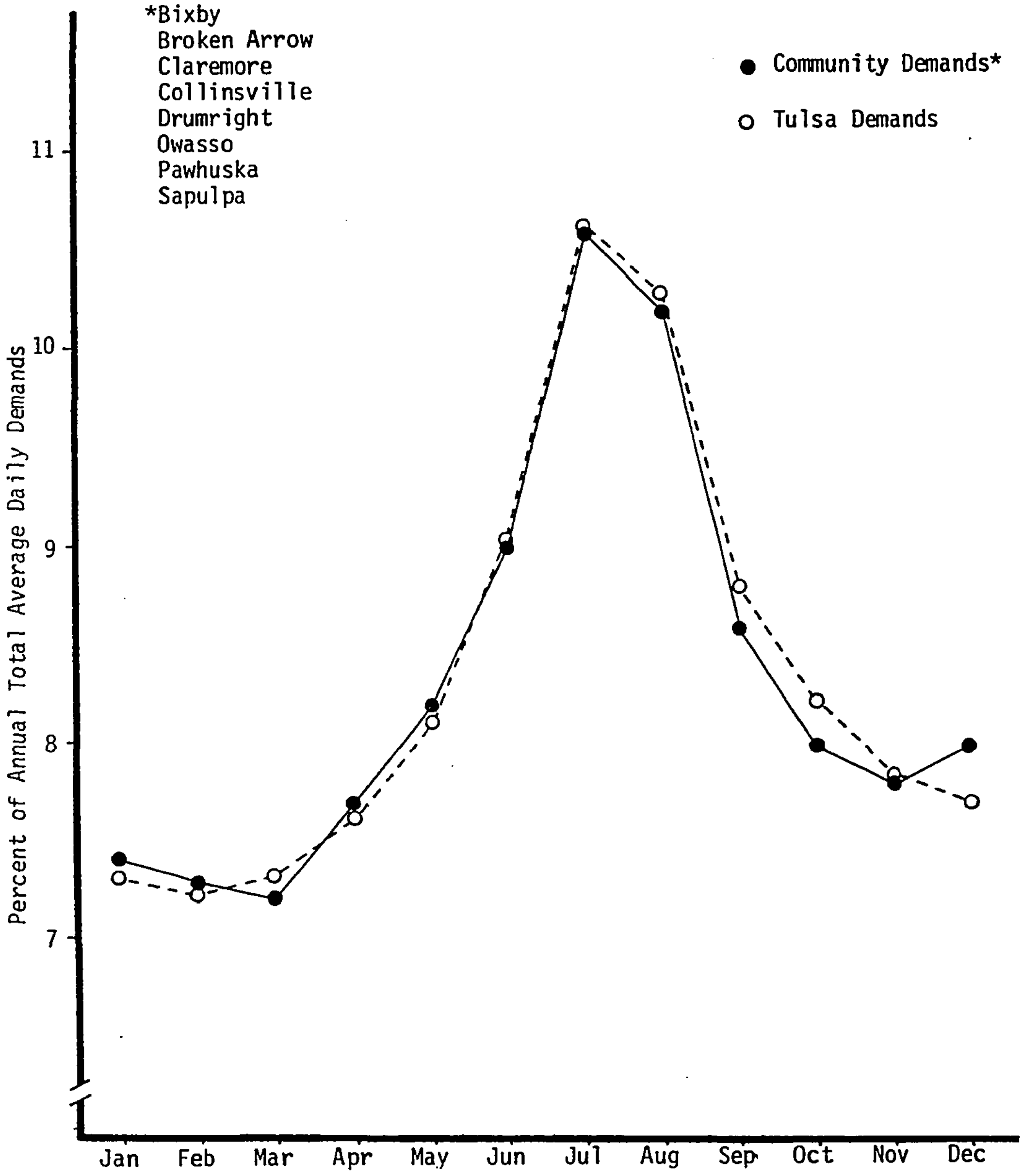


Figure 3.4 Monthly Mean Average Daily Water Demand at Tulsa, Oklahoma and Tulsa Area Communities*, Expressed as Percentages of Annual Demand, 1969-1975

absenses of residents from their dwelling unit during the period of the study required individual adjustments.

## Precipitation Data

Accurate determination of precipitation inputs into the water balance computations for each facility were of particular importance due to the greater volumetric impact of this variable relative to influents and evaporation. Precipitation inputs consist of two components: 1) incident precipitation falling directly onto the water surface and 2) runoff of excess precipitation which does not infiltrate into soils on the inside slopes of the lagoon dikes. The volume of incident precipitation could be directly determined by multiplying precipitation quantity times the average surface area of each lagoon. Determining the volume of precipitation runoff presented a greater obstacle since runoff constitutes only a percentage of the quantity derived from multiplying rainfall by the vertical projection of the dike surface area.

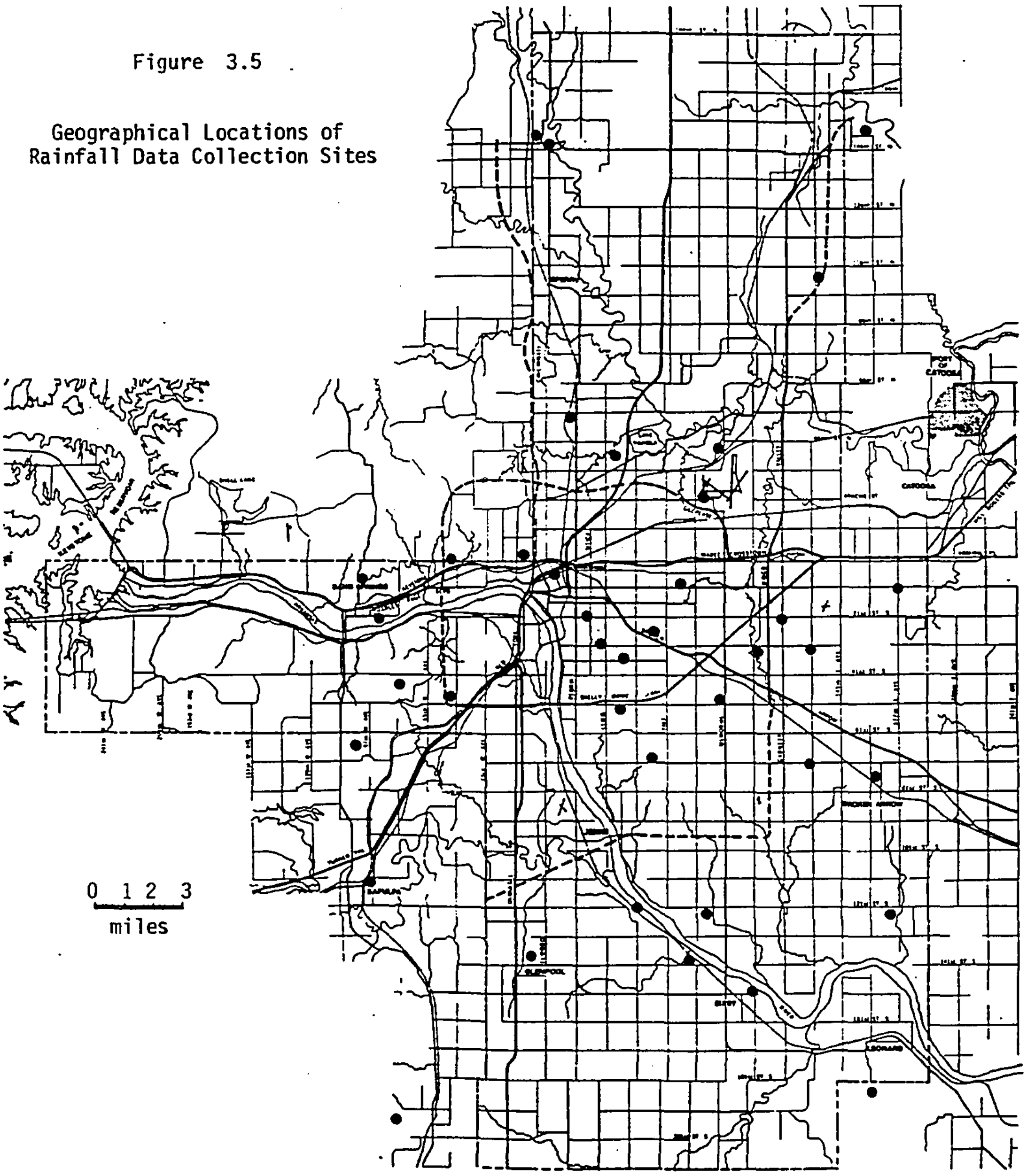
Due to the wide geographical distribution of the study sites, it was not possible to directly measure precipitation quantities at each lagoon following precipitation events without imposing the burden of collecting this data upon the lagoon owners and subjecting the data to questionable accuracy. As an alternative, data from existing rain gauge networks were utilized, along with that from additional gauges established for the project where supplemental data were needed. From these data it was possible to construct isohyetal maps of rainfall distribution for each storm occurring during the data collection period. Figure 3.5 shows the locations of the rainfall gauges relied upon during the course of the study. Data were not received from all gauges shown in that figure for all rainfall events, but were acquired from as many guages as possible following each event. Isohyetal maps of each precipitation event are contained in Appendix C.

The City of Tulsa Engineering Department network of continuous recording rain gauges was utilized extensively, as were rainfall data reports obtained by telephone from gauges established and maintained by operators of water and sewage treatment facilities serving outlying communities in the Tulsa area. Supplemental rainfall data were supplied by private individuals who comprise the Civil Defense rainfall network, the Tulsa Tribune rainfall observers and other individuals. Snowfall data required physical measurements of snowfall depths at rain gauge locations other than the Tulsa recording rain gauges and were converted to water equilavent values based upon water equivalency data determined by the National Weather Service Office at the Tulsa International Airport.

During the course of the study, beginning January 6, 1983, and terminating March 22, 1983, twelve precipitation events were recorded, including three snowfalls. Total cumulative precipitation at each of these facilities varied from only slightly above the approximately five and one quarter inches of precipitation which normally occurs during the period to a maximum of 8.62 inches at one location. As a general rule, greater precipitation occurred in the southern portion of the study area with lighter amounts to the north. Precipitation amounts would have been nearer normal were it not for an unusually intense storm system

Figure 3.5

Geographical Locations of Rainfall Data Collection Sites



which moved through the area in late January resulting in rainfall quantities varying from 2.2 inches to 3.8 inches for this single storm.

Cumulative rainfall at each lagoon site was determined from the isohyetal maps by superimposing a transparent copy of the lagoon site location map (such as that shown as Figure 3.1) over the isohyetal maps and determining precipitation at each site for each event. The results were subsequently accumulated for total study period precipitation quantities at each site.

Determining precipitation runoff quantities from the lagoon dikes required modification of the cumulative rainfall data developed for each site. Initially, an attempt was made to compute precipitation runoff by applying standard infiltration curves to each of the separate rainfall events, based upon the length of the event (see, for example, Viessman, Jr., 1977(11)). However, due to the comparatively steep interior slope of lagoon dikes (approximately 3:1), and the generally heavy, clay based soils of which the dikes are constructed, the accuracy of this methodology was considered questionable.

Based upon historical stream gauging records for the period 1931 through 1960, average annual runoff for the Tulsa area has been found to be approximately 7.5 inches(5). Average runoff from streams in the Tulsa metropolitan area, determined by comparing annual rainfall data with USGS stream gauging records for the period 1964 through 1981 for Hominy Creek, Upper Bird Creek, the Caney River, the Verdigris River and Sand Creek, is consistent with the 7.5 inch reported average runoff figure, ranging from 6.6 inches to 7.7 inches. Runoff analysis conducted by Ray Riley, State Hydrologist with the U.S. Department of

Agriculture, Soil Conservation Service, indicate that the initial 21 inches, approximately, of annual rainfall in Oklahoma are required to satisfy evapotranspiration, with runoff being limited to only a portion of the precipitation in excess of that figure. Evidence of this fact is an obvious break in log data plots of runoff, expressed as percent of annual rainfall, versus average annual rainfall, in inches. The data were based upon stream gauging records for Oklahoma versus annual rainfall for the period 1931 through 1960(12). Riley indicated approximately half of runoff occurring in the eastern portion of the state (in the area where rainfall exceeds 21 inches per year) is due to intensity exceeding the infiltration rate, while the other half is probably due to the soil profile becoming saturated. As a result of Riley's study, average runoff in eastern Oklahoma can be predicted from the equation:

$$Ro = 0.00402x^{2.318}$$

Where: $Ro$ = Runoff as a percent of annual rainfall

$x$ = Annual rainfall in inches

Because of the small watershed areas and steep dike slopes of individual lagoons, the applicability of this average rainfall-runoff relationship to lagoons was questionable. The problem was discussed with Jack Bowman, Hydrologist in charge, and the staff of the National Weather Service, River Forcast Center, in Tulsa, in hope of obtaining runoff coefficients more appropriately suited to determining runoff from lagoon dikes(13). River Forecast Center personnel were unable to assist with specific data or applicable rainfall-runoff relationship coefficients due mainly to the large geographic scale at which their modeling efforts are undertaken. Based upon their recommendations, however, additional study of rainfall-runoff relationships for lagoons in the Tulsa area was undertaken as the most reliable method of developing accurate relationships to be used in the analysis of the data already acquired and for the development of the design model.

Two additional lagoons located in eastern Tulsa County were chosen for the rainfall-runoff study. The facilities were nonresidential lagoons serving a church and parsonage, in one instance, and a truck sales and service firm in the other. The lagoon serving the trucking company was slightly larger than most residential facilities but was otherwise constructed identical to a residential system.

Rain gauges were installed at both locations and lagoon dike and water surface area and elevation measurements taken in the same manner as those for the initial study. Runoff from each precipitation event was estimated by determining the measurable rise in lagoon level above the level measured or projected from trends of rise or recession immediately preceeding the event and subtracting the incident rainfall contribution. The study began in mid September and continued through late December of 1984. Analyses of the rainfall-runoff relationship at these two facilities made it possible to develop runoff estimation techniques for precipitation falling upon lagoon dikes which could be applied both to the data previously collected and that ultimately utilized in the design model.

## Evaporation Data

Determination of evaporation rates has been standardized by the use of standard Weather Bureau Class A pans in which the precise level of water is recorded on a daily basis, correcting for precipitation gains. The pans are constructed of unpainted, galvanized steel approximately four feet in diameter, ten inches deep and mounted twelve inches above the ground(11).

Evaporation from water surfaces is a function of solar radiation, differences in vapor pressure between the water surface and the overlying air, temperature, wind, atmospheric pressure, and even the quality of the body of water. Evaporation rates can be determined by several methods including water budget, energy budget, mass transfer techniques and evaporation pan studies(11). The latter methodology is the most widely used method of determining reservoir evaporation rates and is the one employed in this study.

Average annual Class A pan evaporation rates, as previously determined by the Hydrologic Services Division of the U.S. Weather Bureau, are available for all areas of the United States and widely utilized in hydrologic studies. The average annual Class A pan evaporation for Tulsa, Oklahoma was determined to be 75 inches(14). Weather Bureau data from which this evaporation rate was developed included the period 1946 through 1955. Although the rate is still widely used, a locally longer period of record for pan evaporation data is available in records maintained by the Tulsa District, U.S.Corps of Engineers for each of its northeastern Oklahoma project sites. Historical evaporation data were acquired from that agency for pan installations at Heyburn, Oologah, Keystone, Grand River (Pensacola) and Fort Gibson in northeastern Oklahoma. The period of data collection varies with the project site, ranging from a maximum of 40 years at Grand River Dam to 26 years at Keystone Dam, resulting in a significantly longer period of record than that utilized in the previous Weather Bureau studies. Average annual pan evaporation rates were determined for each of the five Corps sites and were found to vary from 65.45 inches to 73.25 inches with a mean for all sites of 68.73 inches, significantly less than the 75-inch per year Weather Bureau evaporation rate.

Because of the greatly different physical characteristics of Class A evaporation pans, as compared with open bodies of water such as lakes and reservoirs, evaporation rates from pans are significantly greater than those from natural water bodies. It is necessary, therefore, to apply a conversion factor to pan evaporation rates in order to estimate evaporation from larger water bodies. The Class A pan coefficient varies from approximately .6 to .8 across the United States and in the Tulsa area is about .71(14).

Allen Bryant with the Tulsa District, U.S. Corps of Engineers was contacted concerning the acquisition of pan evaporation data during the research period(15). Bryant indicated that the Corps had generally discontinued the local collection of pan evaporation data during the winter months due to freezing conditions and freeze damage to the pans. He indicated that the Corps had conducted a series of winter pan evaporation studies at its impoundments and had developed average winter pan evaporation rates considered to be applicable to normal and drought conditions. The data were collected at the Keystone, Oologah, Heyburn, Markham Ferry, and Fort Gibson project sites and are applicable to the months of January, February and March. The results of the Corps studies are summarized in Table 3.1. It is evident from that table, that some variation does occur in pan evaporation between the collection sites. Bryant observed, during the Corps studies, that the location of the pan with respect to surrounding terrain, vegetative cover, wind current patterns, and other influences noticeably affected pan evaporation rates at each site and, therefore, recommended the use of average rates in conjunction with this lagoon research rather than attempts to measure pan evaporation during the course of the study at one or two locations in Tulsa County.

During the three-month study period of January through March 1983, complete pan evaporation data could be obtained through the Corps of Engineers only for the Heyburn project site. These measurements are also presented in Table 3.1. Reviews of temperature and precipitation recorded during the project indicated that weather conditions deviated somewhat from normal with January being generally warmer than usual and rainfall below normal; February warmer and much wetter than normal, and March slightly cooler and drier than normal.

A cumulative average pan evaporation curve for normal weather conditions for January, February and March was developed from the Corps data by plotting the total cumulative pan evaporation for each month (beginning with an initial value of zero on January 1, 1983) and connecting the points with a smooth curve. This curve is presented as Figure 3.6. The average curve for Heyburn Lake is also plotted in that

## TABLE 3.1

## AVERAGE JANUARY, FEBRUARY AND MARCH PAN EVAPORATION (IN.) UNDER NORMAL AND DROUGHT CONDITIONS AT NORTHEASTERN OKLAHOMA CORPS PROJECT SITES[1]

| MONTH | PROJECT SITE | NORMAL YEAR | DROUGHT YEAR | 1983 |
|---|---|---|---|---|
| January | Keystone | 1.66 | 1.71 | - |
| | Oolagah | 1.98 | 2.32 | - |
| | Heyburn | 2.39 | 2.64 | 2.02 |
| | Markham Ferry | 2.10 | 2.40 | - |
| | Fort Gibson | 1.91 | 2.19 | - |
| | (Average) | 2.01 | 2.25 | |
| February | Keystone | 2.90 | 2.98 | - |
| | Oolagah | 2.65 | 3.25 | - |
| | Heyburn | 2.41 | 2.73 | 1.69 |
| | Markham Ferry | 2.40 | 2.80 | - |
| | Fort Gibson | 2.49 | 2.99 | - |
| | (Average) | 2.57 | 2.95 | |
| March | Keystone | 4.88 | 5.48 | - |
| | Oolagah | 4.63 | 5.17 | - |
| | Heyburn | 4.77 | 5.35 | 3.60 |
| | Markham Ferry | 4.50 | 5.20 | - |
| | Fort Gibson | 4.35 | 5.02 | - |
| | (Average) | 4.63 | 5.24 | |

[1] Source: Tulsa District, U.S. Army Corps of Engineers.

figure in which it is apparent that normal evaporation for Heyburn is very close to that for the average of all project sites combined. The cumulative pan evaporation data for Heyburn during the 1983 study period is also plotted in that figure in which it is obvious that evaporation for the entire three-month period was approximately two inches below normal.

Since normal pan evaporation for the Heyburn site is almost identical to the average for all of the Corps projects, it was appropriate to use the 1983 Heyburn data as the source of evaporation data for the lagoon systems during the period of the study. Individual pan evaporation, in inches, was determined from the 1983 Heyburn curve (Figure 3.6) for each of the thirty-three lagoons included in this study by simply determining the total evaporation which occurred for each facility in between the dates during which it was included in the project. This pan evaporation for each lagoon was subsequently converted to estimated lagoon evaporation by utilizing the 0.71 pan evaporation coefficient previously discussed.

## Residential Demographic Change Analysis

The major emphasis of this portion of the research was to identify predictable relationships or trends in relationships between social and physical variables characterizing single family dwelling units. Many of the significant predictors of household wastewater flows are demographic and social characteristics which, although identifiable at the time the dwelling is constructed, are subject to substantial change as the housing unit is sold or rented and occupied by different families. For

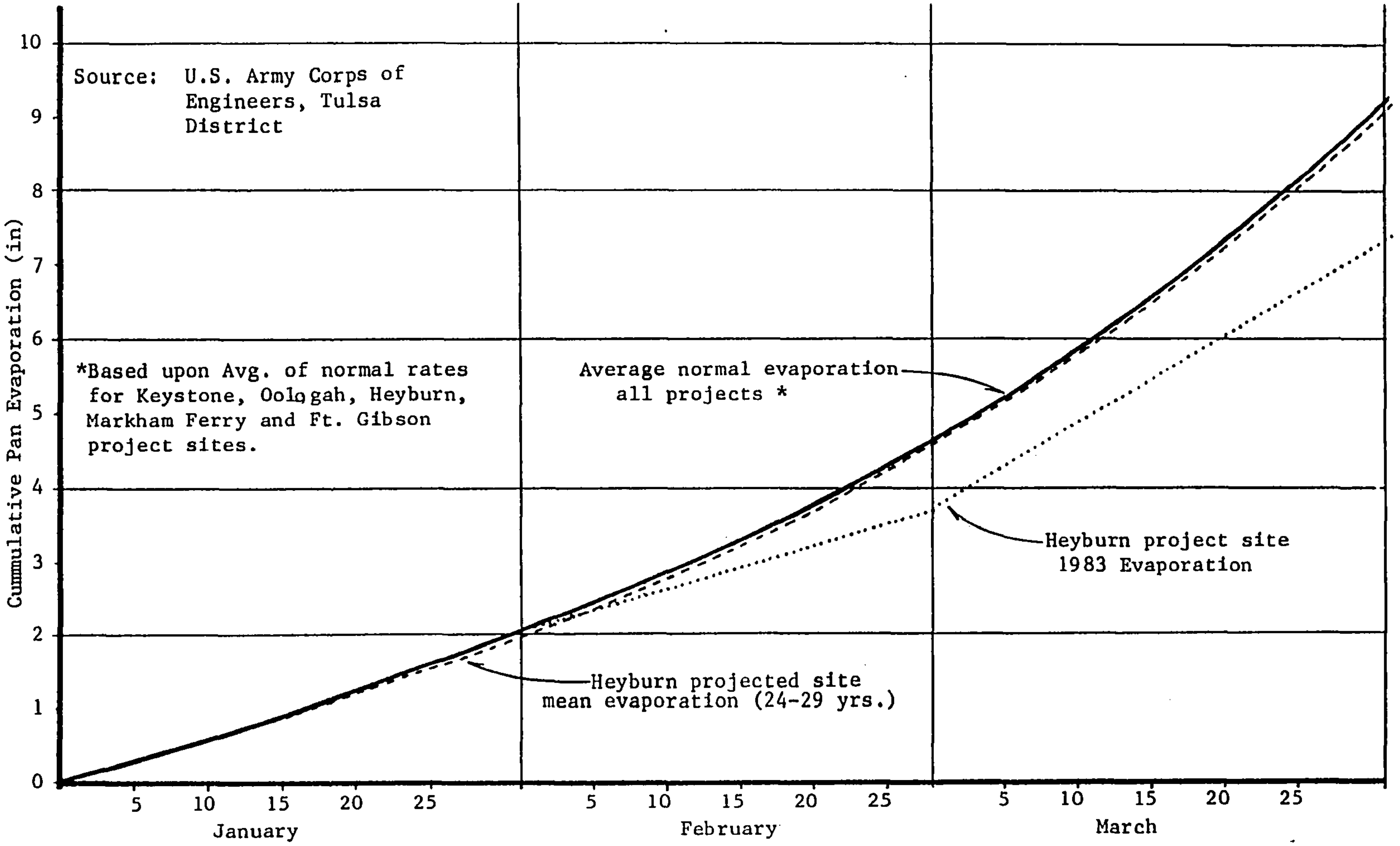


Figure 3.6 Tulsa Area Cummulative Pan Evaporation for January, February and March

this reason it is important for onsite residential lagoons to be designed either on the basis of unchanging physical dwelling unit characteristics (e.g., bedrooms, square footage, etc.) which bear demonstrable relationships to wastewater flows or on the basis of quantifiable social and demographic characteristics of the occupying households which follow predictable trends as they change over time.

Since little correlation can be identified between most physical dwelling unit characteristics and wastewater flows, demographic data for the Tulsa area were examined in the hope of identifying predictable temperal trends in household demographic and social variables which could subsequently be related to wastewater flows. This demographic change analyses relied upon the decennial censuses as the most available and accurate source of local demographic data. By careful selection of Tulsa census tracts which had undergone little or no boundary changes between censuses, it was possible to longitudinally track certain demographic changes occurring in the selected tracts over a twenty-year period by relying upon census data collected in 1960, 1970 and 1980. Census data were drawn from U.S. Census Bureau Census Tracts publications for Tulsa, Oklahoma (16, 17, 18).

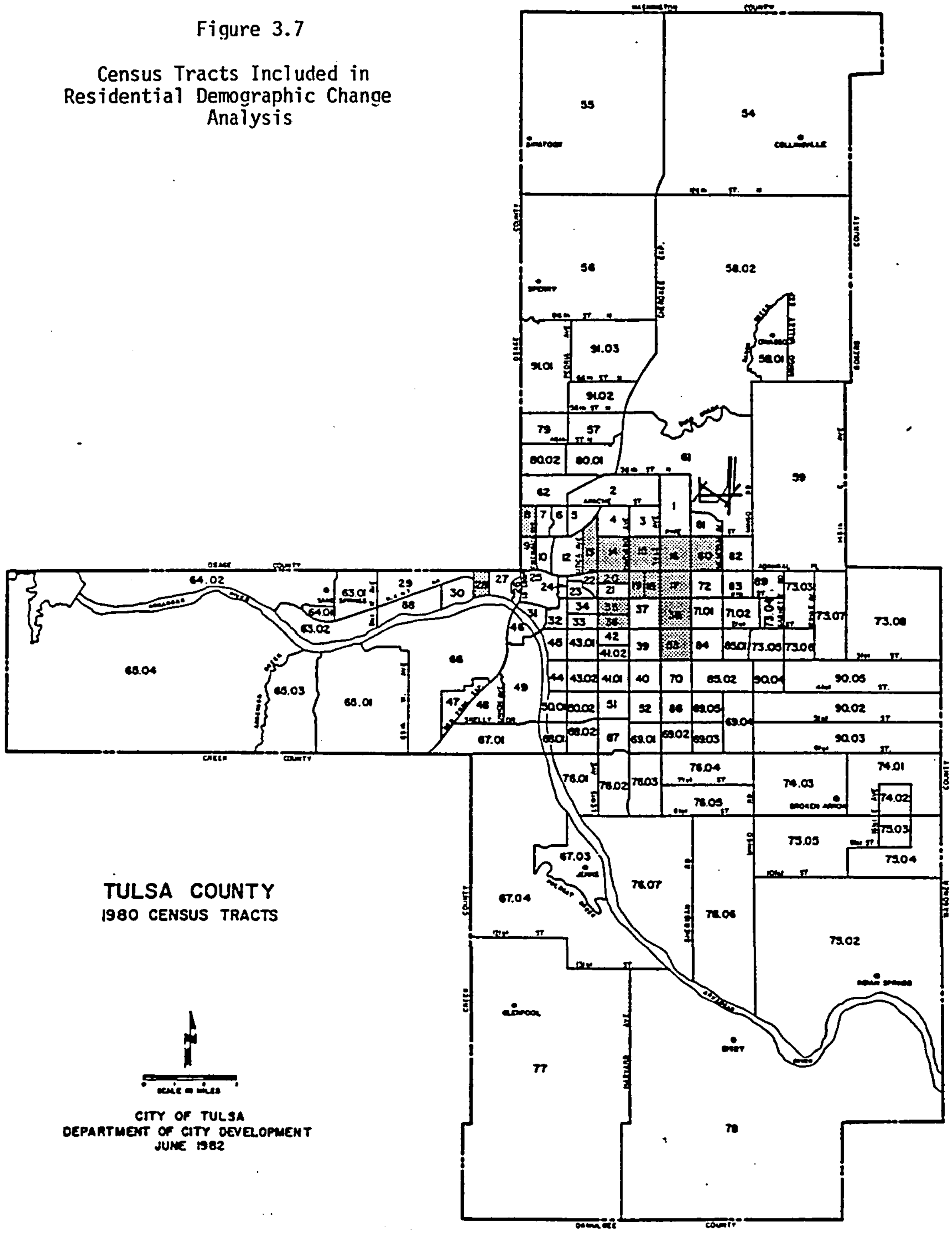
Since the primary aim of the research was to identify characteristic changes in households occupying single family dwelling units, only those tracts containing few or no multi-family dwelling units could be included. Twenty-three census tracts were selected for analysis based upon the insignificant boundary change criterion. After tabulation of the data for these tracts, the number required further reduction to fifteen tracts due to excessive percentages of multi-family dwelling units having been constructed during the 1970 to 1980 decade. Of the fifteen tracts used in the analysis, most exhibited multi-family dwelling unit percentages less than one percent in 1960 with the highest being 6.9 percent. These figures had increased by 1980 to range from 1.8 percent to 12.8 percent. The fifteen tracts included in the analysis were Tulsa, Oklahoma census tracts numbers 8, 13-20, 28, 35, 36, 38, 53 and 60. The geographical locations of these tracts are shown in Figure 3.7.

Census data tabulated for the analysis included population counts by age category, numbers of dwelling units by date of construction, numbers of rooms, numbers of persons per dwelling unit, owner and renter occupancy and numbers of bathrooms. Some of the data were modified through the calculation of percentages, median values, etc., as required for the particular analysis undertaken. In addition to the increase in the number of multi-family units exhibited by each of the tracts between censuses, there was a significant decline in the total population of nearly all tracts even though some tracts gained in number of housing units.

Although U.S. Census Bureau data are highly regarded from a reliability standpoint, since they are based upon respondent-completed questionaires, they are subject to a certain degree of error. A salient example of this is evident in the analysis of housing data characteristics. In some census tracts, the total count of housing units reported built during some prior decades at the time of the 1960 census actually increased in subsequent censuses, an obvious impossibility. The reason for this phenonemon probably stems from owner

Figure 3.7

Census Tracts Included in Residential Demographic Change Analysis



lack of knowledge as to the actual construction date of their dwelling unit or, possibly, the tendency to report owning a newer dwelling unit than is actually the case. Typically, during the 1970 and 1980 censuses the number of dwelling units constructed prior to 1939 and during the decade of the 1940's tended to decrease. While this trend is possible, since older dwelling units are destroyed from a variety of causes, the number of dwelling units reported constructed during the 1950's and 1960's was often falsely inflated. The dwelling unit age reporting errors were not large enough, fortunately, to significantly mask longitudinal trends in demographic data relating to age of housing, although they likely did contribute to the variance of these relationships.

## Statistical Methods

The analyses performed on all of the data obtained during the course of this research, including both household and field survey data, as well as historical precipitation, evaporation and census data, relied heavily on inferential statistics. Mathematical computations, hypothesis testing and result interpretations were guided by procedures presented by William L. Hayes(19) and Afifi and Azen(20). The specific statistical techniques employed were dictated by analytical requirements appropriate for the data and their intended uses. Since the primary objective of the research was the development of an onsite lagoon design model, based upon the predictive relationships among demographic and social variables and wastewater flow characteristics, correlation analysis and simple and multiple regressions were greatly relied upon for the development of predictive equations. Both linear and curvalinear regression models were developed to provide the best explanation of data variability in simple regression analyses. Data sets were subjected to regression comparison testing utilizing linear, power curve, logarithmic and exponential curve fits to obtain greatest variance reductions. In some instances, second and third degree polonomial curve fits were also employed.

Multiple regression analyses of data were carried out, as appropriate, with the data both in original form and following power and partial power transformations to achieve greatest residual sum of squares reductions. One-way analysis of variance was also employed in some cases to test the significance of differentials between sums and measures of central tendency for entire or partial data sets. In those instances in which the application of analysis of variance and regression analysis were unable to provide meaningful explanations of data variances, data interpretation was aided by the use of probability analysis including frequency distributions and corresponding determinations of exceedences and return periods. With regard to the important, largely unpredictable, water balance parameters of precipitation and evaporation, probability analysis provided the most appropriate and meaningful analytical technique available.

The results of the statistical analyses of all data are presented with their corresponding text and include interpretations of statistical significance and predictive equations. All analyses were performed by computer, relying upon statistical programs developed in-house by the Office of Planning and Research of the Tulsa City-County Health

Department based upon mathematical formulae of Afifi and Azen(20). The general forms of the simple, linear and curvalinear regressions and multiple regression models are presented below:

| | |
|---|---|
| Linear Regressions | $y = mx + b$ |
| Power Curves | $y = ax^b (\ln y = b \ln x + \ln a)$ |
| Logarithmic Curves | $y = a + b \ln x$ |
| Exponential Curves | $y = ae^{bx} (\ln y = \ln a + bx)$ |
| Multiple Regressions | $y = m_1 x_1 + m_2 x_2 \ldots + m_i x_i + b$ |

Where:

$y$ = estimated value of $y$

$m, m_i$ = linear regression coefficient

$x, x_i$ = sample value of $X$

$b$= y axis intercept (constant)

$a$ = regression coefficients of exponential, logarithmic and power curves

$e = 2.71828$

$n$ = number of variable pairs

ln = natural logarithm

# CHAPTER IV

# RESULTS AND DISCUSSION

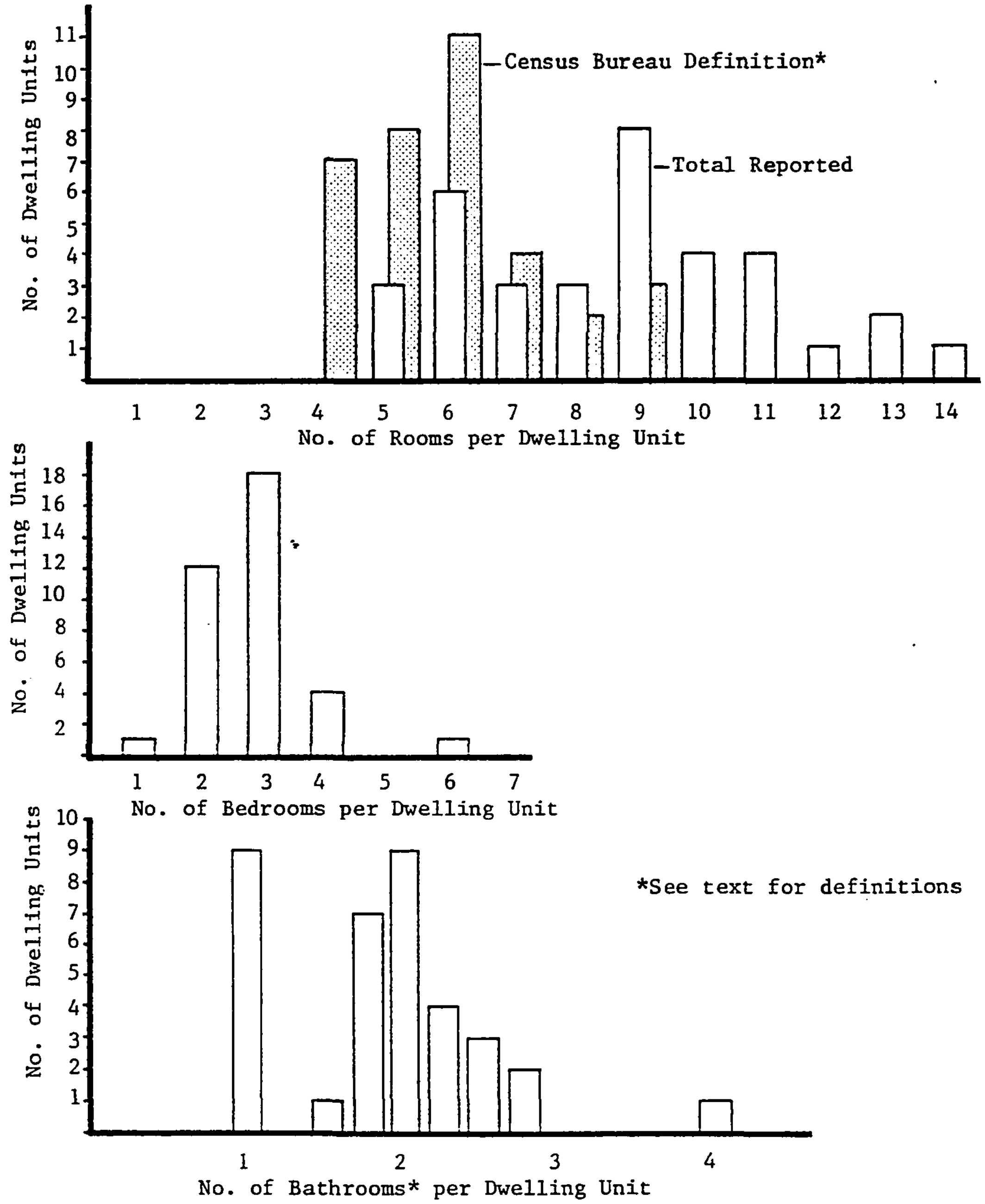
## Household Survey Results

Household survey data were acquired from thirty-six dwelling units served by thirty-three lagoon systems (three lagoons serve two separate dwelling units). Eighty-three percent of the responding dwelling units were owner-occupied and six were rental units. Twenty-six of the dwelling units were classified by respondents as site-built houses, eight were classified as mobile homes, and two were classified as manufactured homes. After site inspections were made, two dwellings classified as manufactured homes were reclassified for analytical purposes on the basis of their general construction, one into the mobile home category and one into the site-built category.

Responses to the questionaire were generally quite complete although only twenty-two of the dwelling units, or approximatley sixty-one percent, provided information as to the initial cost of their dwelling unit. The relatively low response to this item, as compared to other questionaire items, was not unexpected since responses to income related questions are typically low on such questionaires. Responses to certain household activity questions, particularly, loads of dishes washed, loads of laundry washed, and number of baths and showers taken, were missing for some dwelling units (especially rental units) since the person completing the questionaire did not have access to that information. In such cases, the data were not utilized in subsequent analysis.

The oldest dwelling unit including in the survey was built in 1977 with the newest completed just prior to commencement of the study. The median age of all dwelling units was 3.1 years equating to a median construction date of mid 1980. The reported number of rooms per dwelling unit ranged from five to fourteen, averaging 8.69, with a median of 9.75. Under the U.S. Census Bureau definition of rooms, which excludes bathrooms, hallways, utility rooms, half rooms, etc., the number of rooms per dwelling unit ranged from four to nine with a corresponding average and median of 5.86 and 6.14, respectively. Numbers of bedrooms per dwelling unit ranged from one to six with the most frequent being three. Graphical distributions of numbers of rooms and bedrooms per dwelling unit are presented in Figure 4.1.

Numerical classification of bathrooms was based upon a system of quarters in which a full bath included a lavoratory, toilet and bathtub; a three-quarter bath included a lavoratory, toilet and shower only, and a half bath included only a lavoratory and toilet. Utilizing this system, the number of bathrooms reported per dwelling unit ranged from one to four. Twenty-five percent of dwelling units reported either exactly one or two full bathrooms. Approximately seventy-five percent of all dwelling units reported having more than one bathroom. Graphical distributions of numbers of bathrooms per dwelling unit are also



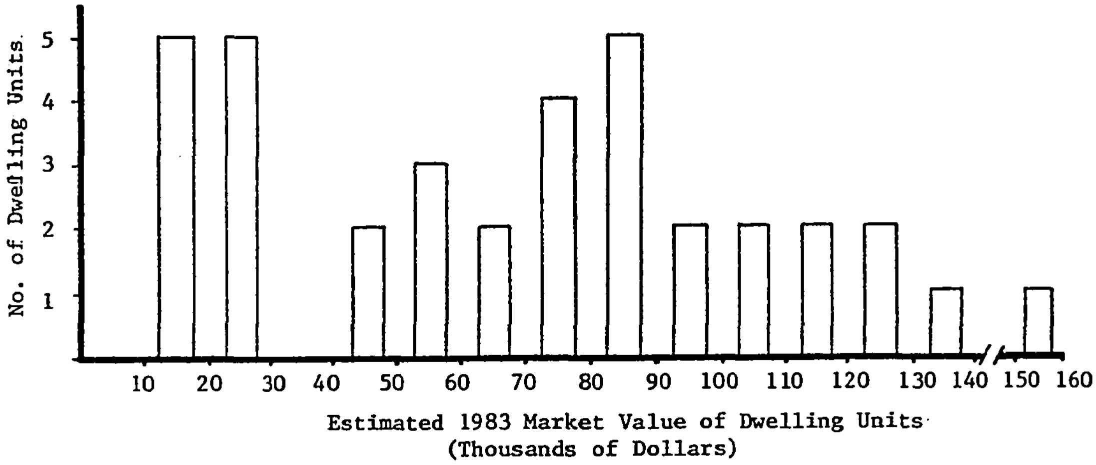
*See text for definitions

Figure 4.1 Distributions of Surveyed Dwelling Units by Numbers of Rooms, Bedrooms and Bathrooms presented in Figure 4.1.

Twenty-seven of the thirty-six dwelling units surveyed reported having automatic dishwashers, six reported no automatic dishwasher in the unit and three did not respond to this question.

The dwelling units included in the study exhibited a broad range of sizes and estimated values. Reported floor areas (i.e. heated floor area, garages excluded) ranged from 784 square feet to 4600 square feet. Estimated current (1983) market value of the dwelling units, which was determined for descriptive purposes only since the response to this question was limited, ranged from $14,400 to $184,000. Distributions of dwelling unit square footages and estimated current values are presented in Figure 4.2.

Moderate to strong direct statistical correlations between certain dwelling unit structural variables were identified including: 1) number of bathrooms and total number of rooms per dwelling unit, 2) square footage of floor space and total number of rooms per dwelling unit, 3) number of bathrooms and square footage of floor space per dwelling unit, and 4) number of bedrooms and total square footage of floor space per dwelling unit. The relationship exhibiting the greatest variance and weakest corresponding correlation was that of number of bedrooms and square footage of dwelling units. Inclusion of two dwelling units in the analysis which were comparative outlyers in terms of these variables (one with an unusually large number of bedrooms and bathrooms for its square footage and another with an unusually large square footage for the number of rooms, bathrooms, and bedrooms it contained) considerably increased the variance of these analyses and significantly altered the



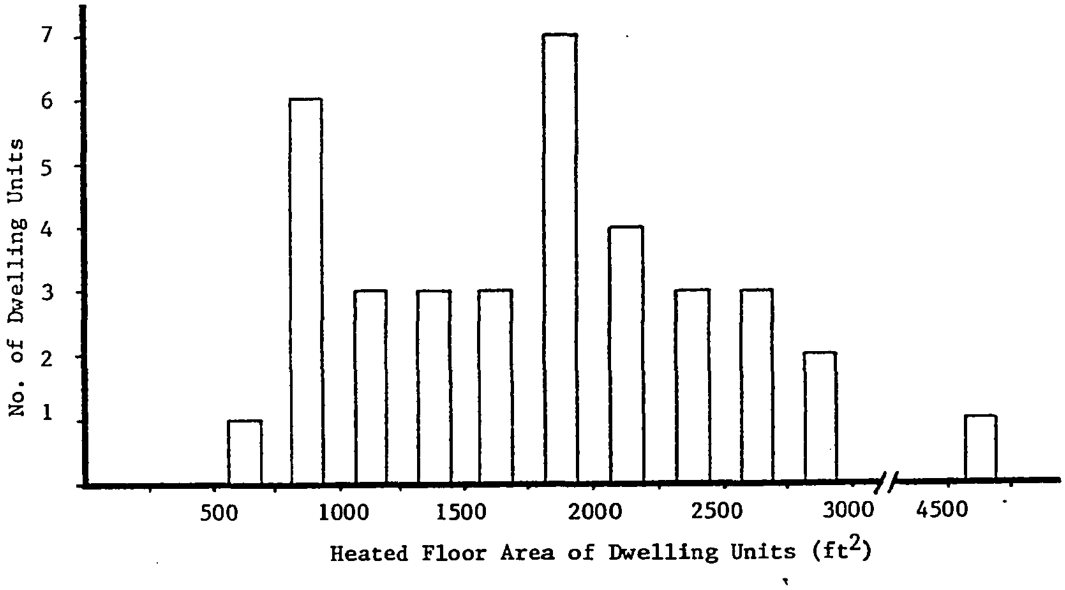


Figure 4.2 Distributions of Surveyed Dwelling Units by Estimated 1983 Market Value and Heated Floor Area

slopes of the regression lines. Removal of these two outlying data points to improve the accuracy of the regressions from any subsequent secondary analysis utilizing these data is probably justifiable. Data plots for the structural parameters are shown in figure 4.3.

Thirty-two of the thirty-six households provided age data for household occupants. These households included 108 individuals representing a broad range of ages, the youngest participant being six months of age and the oldest 79 years. The age distribution, by five-year age groups, of participating dwelling unit occupants is shown in Figure 4.4. Given the relatively small size of the study group, the age distribution of the participants favorably approximates that of Tulsa County and the United States. Fifty percent of participating households included children nineteen years of age and younger with this age group representing 34.3% of the total participating population. Six housing units contained individuals over the age of 60 years with this age group comprising 7.4% of the total participating population.

The median household population was 4.3 compared with an average household population of 3.2. While the total number of residents per dwelling unit ranged from one to six, one- and two-member households comprised 41.2% of the participating dwelling units. The overall distribution was as follows: one-member households, 3%; two-member households, 38%; three-member households, 15%; four-member households, 29%; five-member households, 12% and six-member households, 3%.

## Lagoon Survey Results

The lagoon systems included in the study varied considerably in both

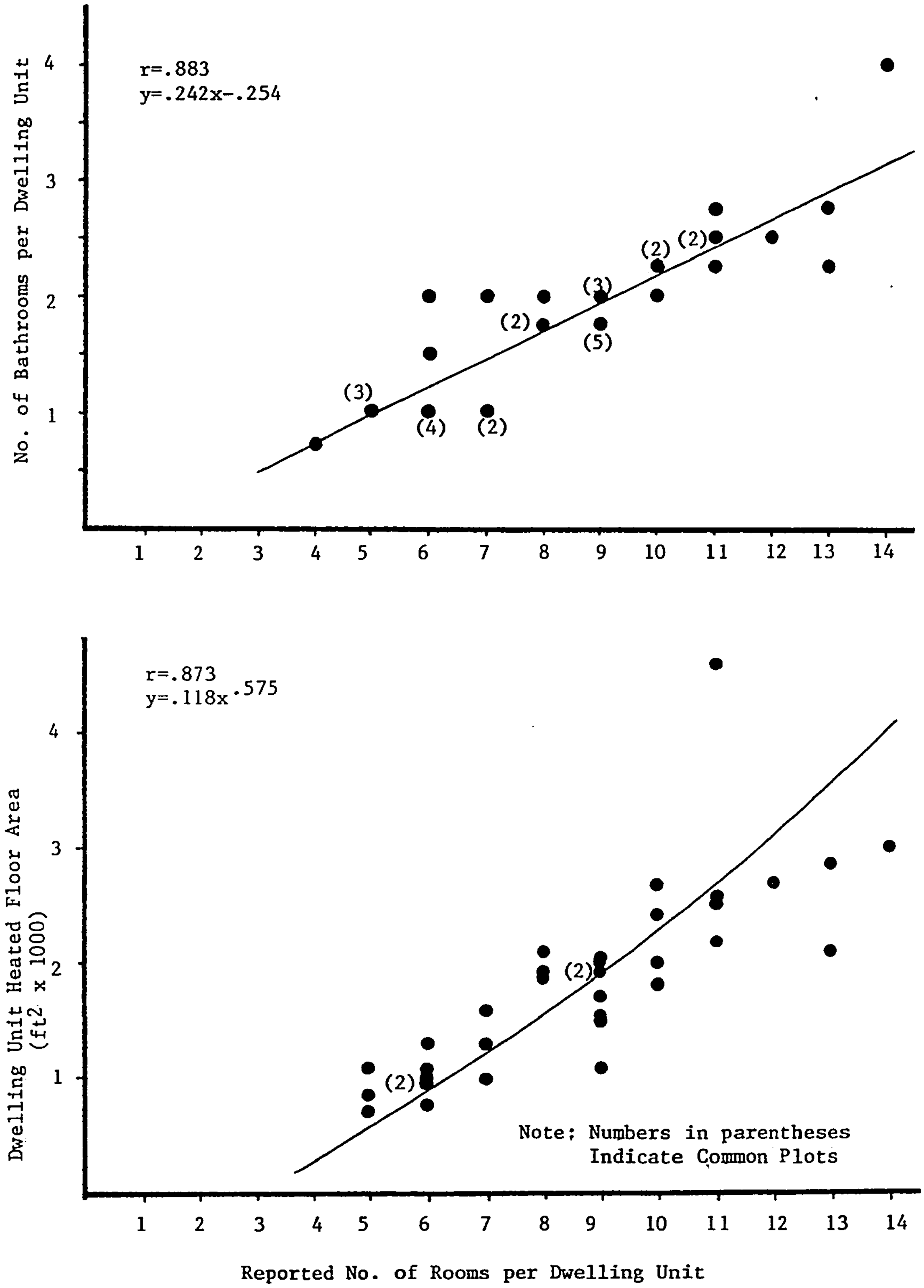


Figure 4.3a Number of Bathrooms and Dwelling Unit Heated Floor Area Versus Number of Rooms per Dwelling Unit

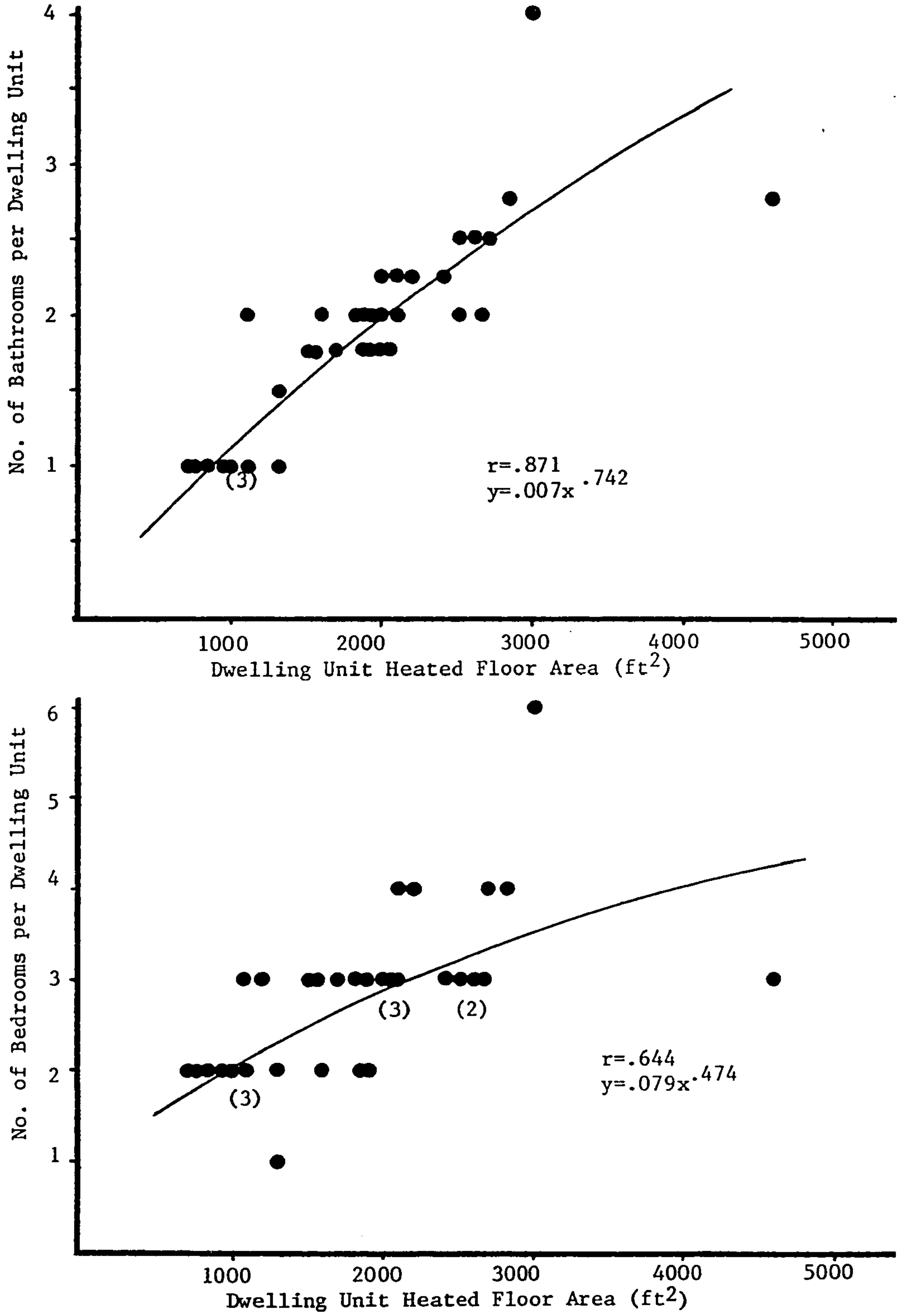


Figure 4.3b Number of Bathrooms and Number of Bedrooms Versus Dwelling Unit Heated Floor Area

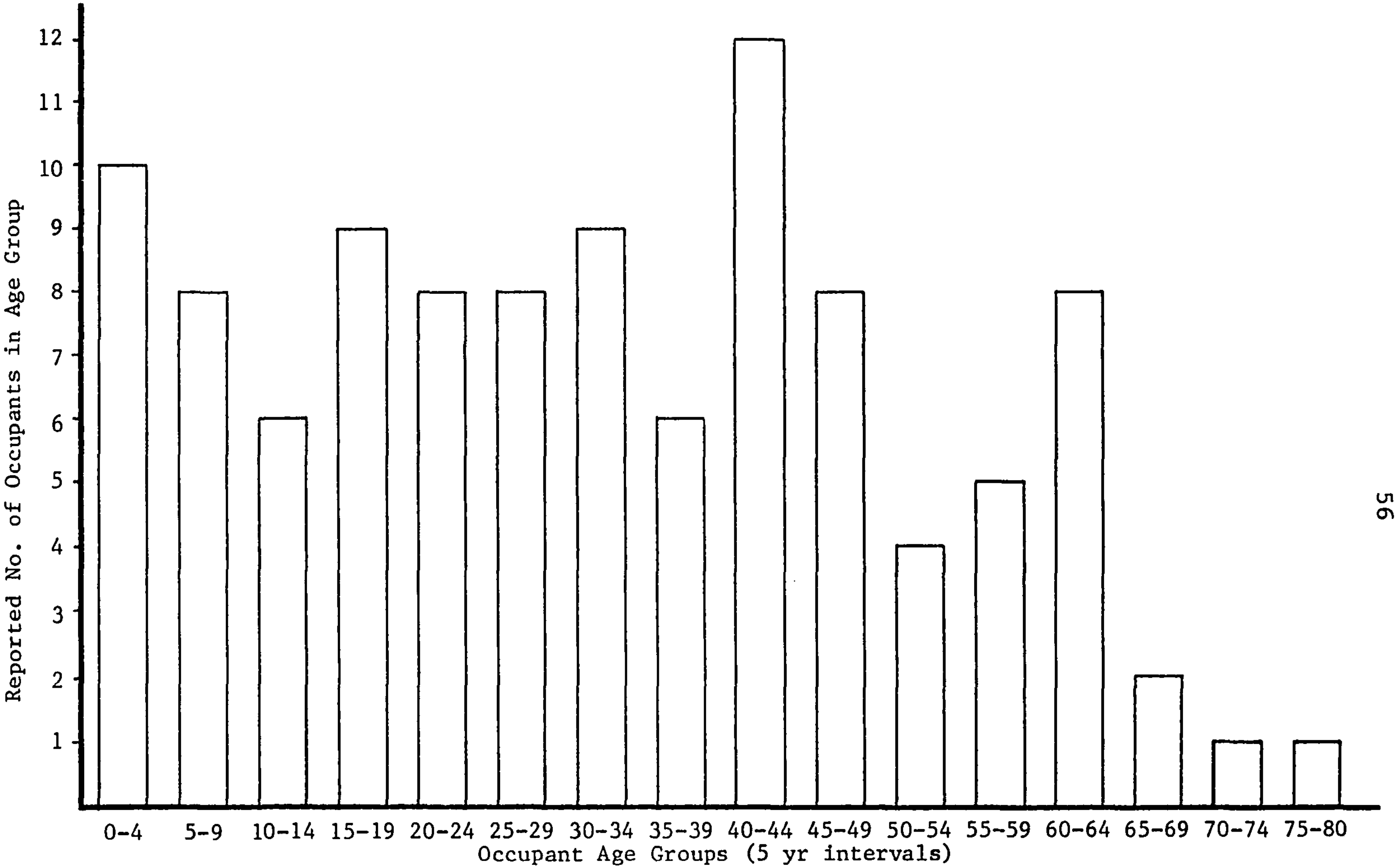
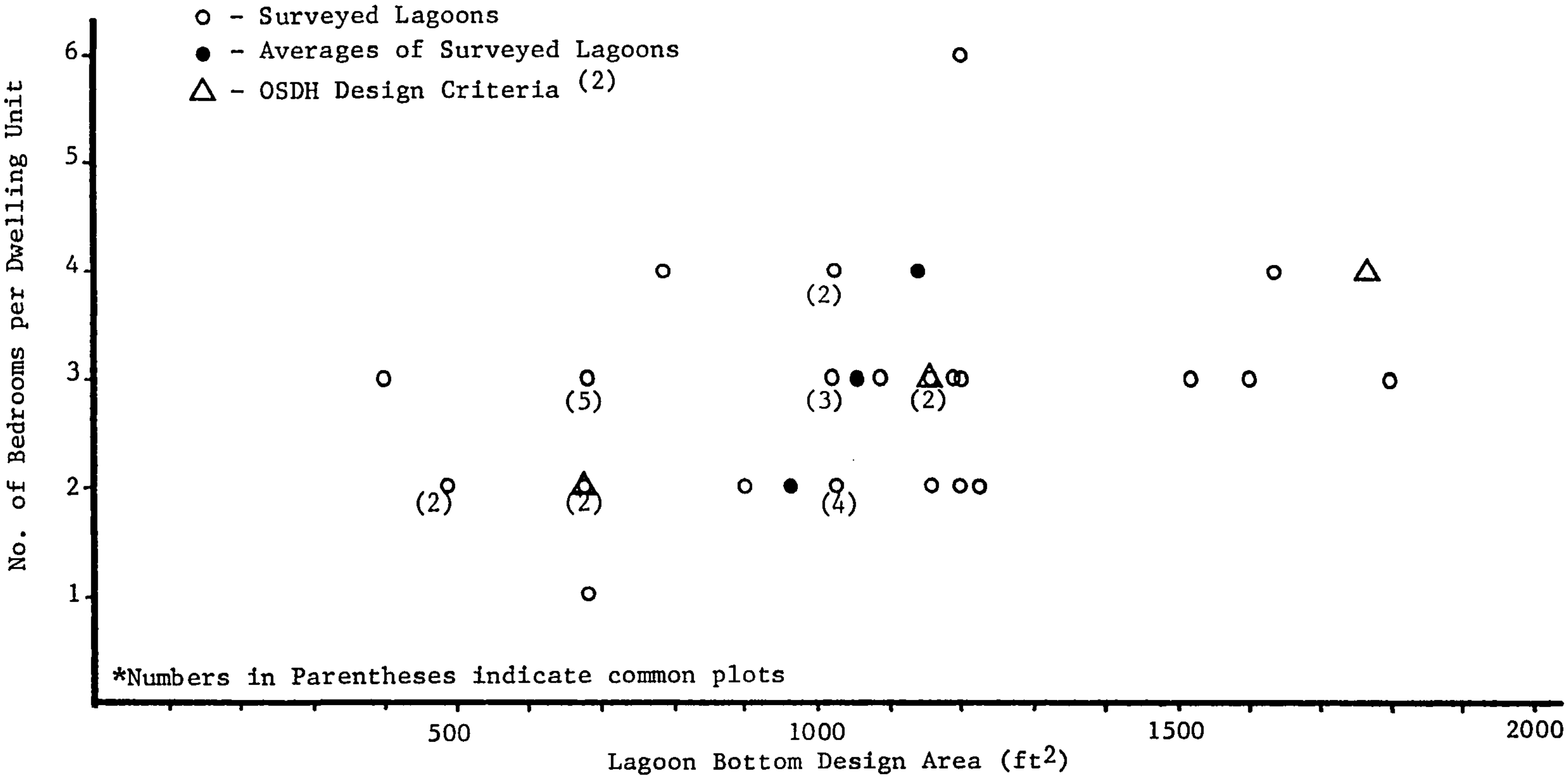


Figure 4.4 Age Distribution of Surveyed Dwelling Unit Occupants

physical design characteristics and degree of proper maintenance. Although current state design criteria(1) specify lagoon depths of seven feet (see appendix A), design depths of both six and seven feet have been commonly allowed in the past. Of the thirty-three systems included in this study, nineteen were seven feet deep, eleven were six feet deep, one was nine feet deep, and one was ten feet deep. The bottom design square footage of these facilities ranged from 400 square feet for the smallest system to 1800 square feet for the largest. As operating experience with the design of the systems was gained following their inception in the mid 1970's, the dimensions of the systems were gradually reduced as it became apparent that many were overdesigned and operating depths were too shallow. Strict adherence to state design criteria applicable to Tulsa County (see Figure 2.2) would result in lagoon designs for two-, three-, and four-bedroom dwellings with bottom areas of 676 square feet, 1,156 square feet, and 1,764 square feet, respectively. In actuality, reviews of the final inspection design data for the facilities included in this study showed a considerable range of design sizes as shown in Figure 4.5. The average design bottom areas for surveyed two-, three-, and four-bedroom dwellings were 968 square feet, 1,051 square feet, and 1,145 square feet, respectively. It is evident from these data, that the systems currently operating in the Tulsa metropolitan area are designed with a significantly narrower range of sizes, on the average, than specified by state standards.

The onsite lagoon systems included in the study reflected considerable variance in operating depths. Although operating depths were not measured during the field survey, these depths could be



*Numbers in Parentheses indicate common plots

Figure 4.5 Bottom Design Area of Surveyed Lagoons by Number of Bedrooms per Dwelling Unit computed from record design bottom dimensions, in conjunction with field measurements of water surface area, dike dimensions, and calculated side slopes. Figure 4.6 shows the graphical distribution of calculated average operating depths of the participating lagoons in 0.5 foot intervals. It is apparent in that figure that the majority of systems studied were operating at depths between three and five feet. Assuming that the design operating depth for all systems includes a two-foot freeboard, the average operating depth of all systems (including both four- and five-foot depth lagoons) should have been approximately 4.8 feet during the period of the study (the systems would have been operating at approximately their maximum design depth due to unfavorable wintertime evaporation and precipitation conditions). In actuality, the median operating depth of the thirty-three systems was 3.75 feet (mean operating depth was 3.71 feet), approximately a foot below that which would have been anticipated at the time of the study.

These data suggest that the systems are, on the average, operating below their optimum design capacity and, as a group, are probably overdesigned. Additional evidence to support this proposition are the field observations of aquatic vegetation established in some of the lagoons. Analysis of the field data indicates sixty-four percent of the systems exhibited no rooted aquatic vegetation with fourteen percent having limited rooted vegetation. An additional fourteen percent exhibited moderate growths of rooted aquatic vegetation with approximately seven percent having abundant growths of such vegetation. The existence of rooted aquatic vegetation in the systems, particularly cattails, reflects past conditions of shallow operation which allowed

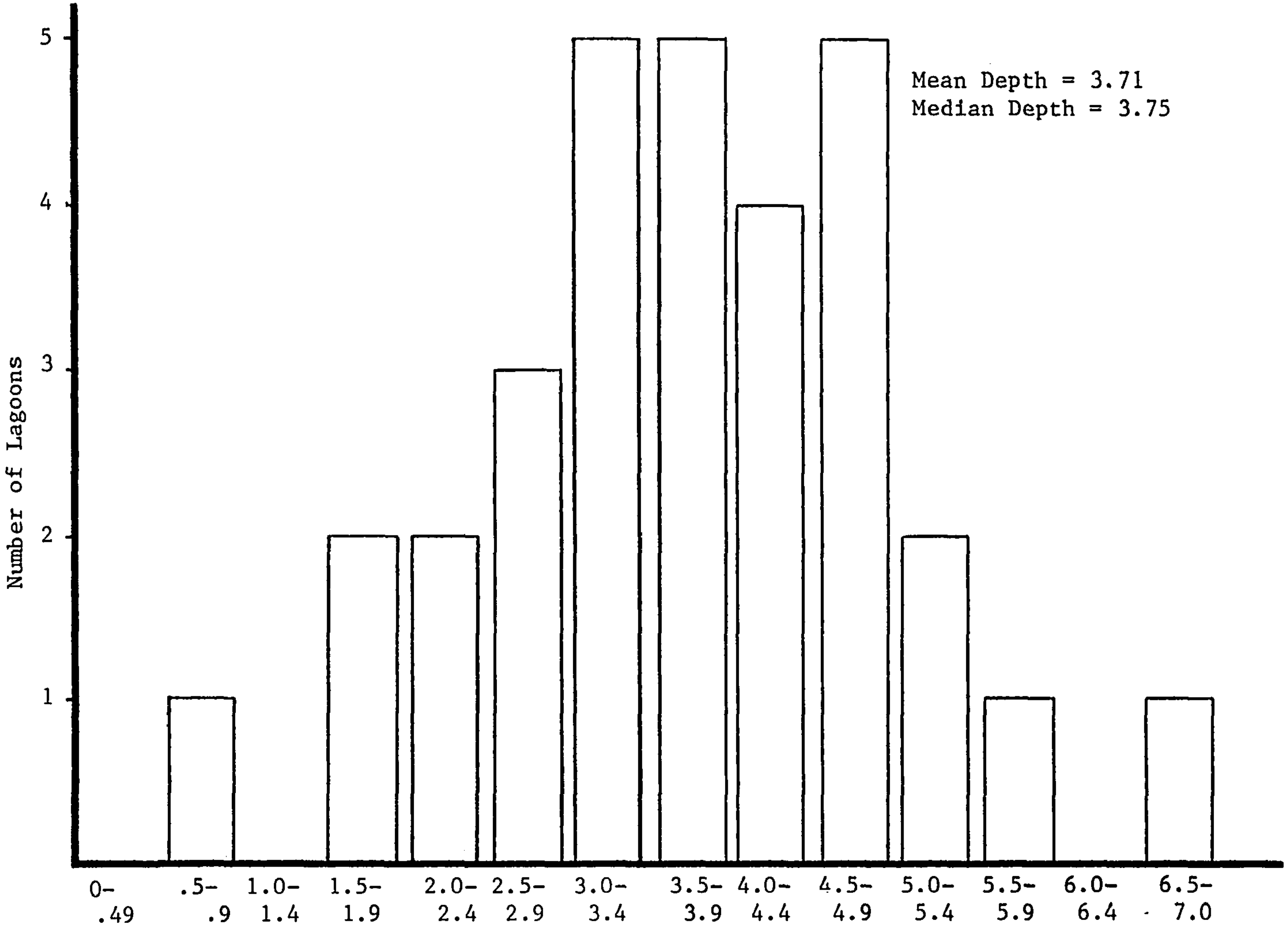


Figure 4.6 Distribution of Surveyed Lagoons by Calculated Study Period Average Operating Depth

vegetation to become established, probably during dry summer conditions. Once such vegetation is established, it is difficult to control. The existence of rooted vegetation growths can also be an indicator of bank erosion and siltation in some areas.

Most of the lagoon systems were essentially square in shape although some were rectangular as a result of specific site requirements. Only one system exhibited a length more than twice its width. The extent of rounding at lagoon corners varied from virtually no rounding to one extreme cases in which the facility was nearly circular.

Oklahoma State Standards(1) for construction of onsite lagoons specify dike side slopes should be 3:1 or less while the EPA design manual, Onsite Wastewater Treatment and Disposal Systems(3) suggests the slopes should be between 3:1 and 2:1 for purposes of controlling rooted aquatic vegetation while still maintaining erosion resistance. Side slope calculations completed on the participating lagoon systems showed that, while the majority of systems had slopes approximating the 3:1 recommendation, they varied from as steep as approximately 2:1 for four systems to as shallow as 4:1 for three systems.

Table 4.1 presents a summary of the results of the field inspections of the participating systems with regard to fencing, dike maintenance, dike vegetation, erosion, and aquatic vegetation. Broad classifications of vegetation types found to be established in significant quantities on the lagoon dikes were noted at the time of the initial visit to each facility. A single lagoon might exhibit several types of vegetation and, for this reason, many of the percentages shown for the types of vegetative cover in Table 4.1 do not add to 100%.

## TABLE 4.1

## SUMMARY OF SURVEYED LAGOON SYSTEM SITE INSPECTION DATA

| CATEGORY | | CONDITION | NUMBER | PERCENT |
|---|---|---|---|---|
| Fence | | Good | 10 | 58.8 |
| | | Fair | 5 | 29.4 |
| | | Poor | 2 | 11.8 |
| | | Fenced | 17 | 60.7 |
| | | Unfenced | 11 | 39.3 |
| Dike | | | | |
| | Maintenance | Mowed | 12 | 42.8 |
| | | Unmowed | 16 | 57.2 |
| | Erosion | None | 14 | 50.0 |
| | | Slight | 6 | 21.4 |
| | | Moderate | 5 | 17.9 |
| | | Severe | 3 | 10.7 |
| Dike Vegetation | | Weeds | 14 | 50.0 |
| | | Brush | 8 | 28.6 |
| | | Trees | 5 | 17.9 |
| | | Barren Areas | 12 | 42.9 |
| | | Grass (only) | 5 | 17.9 |
| | Fenced | Mowed | 4 | 20.0 |
| | | Unmowed | 16 | 80.0 |
| | Unfenced | Mowed | 8 | 61.5 |
| | | Unmowed | 5 | 38.5 |
| Aquatic Vegetation | | None | 18 | 64.3 |
| | | Limited | 4 | 14.3 |
| | | Moderate | 4 | 14.3 |
| | | Abundant | 2 | 7.1 |

Although some of the systems exhibited moderate, and in three cases, severe dike erosion, erosion was not a major problem for most facilities. Poor establishment of adequate dike vegetation in the form of soil stabilizing grasses which would prevent erosion problems was noted in many cases. Forty-three percent of the systems surveyed exhibited significant barren areas with no vegetative cover of any kind making these areas subject to future erosion. In most cases, the barren areas were notably devoid of topsoil which would prevent the establishment of quality vegetation.

Although fencing of onsite lagoon facilities is a requirement of Oklahoma State Standards(1), thirty-nine percent of the systems surveyed were unfenced leaving sixty-one percent with some form of fencing. Some of the systems were located within fenced pastures but were not fenced immediately adjacent to the facility itself. In some of these instances, livestock were allowed to water from the facilities. Although fencing of onsite lagoons is unquestionably important from the standpoints of public health and child safety considerations, the data undeniably support the observation that fencing interferes with proper maintenance of the facilities. In some instances, fences surrounding these facilities did not contain gates through which access could be gained for carrying out proper maintenance.

The existence of rank growths of trees, brush and other vegetation on lagoon dikes may block beneficial wind action and shade the lagoon water surface reducing photosynthetic oxygen production thereby significantly interfering with the proper functioning of these facilities. Of the twenty facilities which were properly fenced, only thirty-three percent were mowed leaving seventy-six percent unmowed. Conversely, sixty-seven percent of the unfenced facilities were mowed leaving only twenty-four percent unmowed. Similarly, of the lagoons with fenced dikes, sixty-five percent supported weeds, twenty-five percent supported trees, and thirty-five percent supported brush in significant quantities. Of the unfenced lagoon dikes, only twenty-three percent supported weeds, eight percent trees, and fifteen percent brush. The percentage of lagoons exhibiting significant barren areas was, however, somewhat higher for the unfenced facilities than for the fenced facilities, perhaps as a result of the greater human or animal traffic over the dikes of these systems.

## Household Wastewater Flow Characteristics

As previously documented, residential water consumption and wastewater flow rates are very closely related, particularly during winter months when outdoor water use is limited. For this reason, water use measured during the course of this study was assumed to equate directly with residential wastewater flows. Water consumption can vary considerably, reflecting both natural and human influences, from climatic conditions to variations in local economies. These variations result from differences in consumption not only at the individual residential level but also, on a macro scale, among communities and distribution systems as well.

## Literature Review

In 1973 the Water Use Committee of the American Water Works Association published a report(21) listing some of the major factors influencing trends in water use. These included: 1) changes in customer bills, 2) changes in modes of living, 3) growth in major businesses, 4) industry and institutional services, 5) annual and long-term variations in the state of local economies, 6) changes in climatic conditions, 7) development in the existing service area, 8) redevelopment, and 9) availability of adequate water supplies. Only a portion of these factors may influence residential water consumption trends, and the residential wastewater flows of importance to this research.

The Water Use Committee report noted several cases in which customer usage records indicated consumption tended to decrease following significant increases in water rates. It was noted that consumer usage in areas charging sixty cents to seventy cents per thousand gallons, at the time of the report, averaged only approximately seventy percent of usage in areas in which the cost was twenty cents to thirty cents per thousand gallons. However, an EPA funded study at the University of Alabama by Helms and Vallery(22), concerning the residential demand for water, found that water consumption is relatively insensitive to price, except for conservation induced by the knowledge that a price must be paid for water. Within the overall range of price elasticity, they found the price effect is greater at lower incomes and at lower prices. They found little evidence that price elasticity for irrigation (sprinkling) water was greater than that of water for other uses but concluded that summer demand is more sensitive to income.

The Water Use Committee report is one of many sources which has noted the influence of climate, particularly rainfall, on average and peak consumption rates throughout the United States. This is largely due to increased use of irrigation water. N.L. Chan(23) categorized water use into two major components: indoor and spinkling. He observed that water use patterns vary by region and according to family income, type of housing, and water rates. Interestingly, a 1977 study by the Tulsa City-County Health Department(10) found consumption for several study areas in the City of Tulsa to be more closely correlated (r = .848) with average monthly temperature than with average rainfall. Average peak water consumption is not of great importance to this research since sprinkling and irrigation water do not represent return flows to the wastewater treatment systems of residential users.

Of the water system variables potentially influencing water consumption and, consequently, wastewater flow at the individual residential level, those of most importance include water price and water system pressure. As previously discussed, while there is some indication that water price may influence demands, this influence is apparently small. Richard Schaefer(24) cites five separate studies which..."have shown that incentives to reduce water use are primarily a function of income".

While it is reasonable that water consumers in higher income brackets would tend to consume more water for unessential uses such as lawn watering, less variance might be expected for indoor uses (i.e., for "essential" uses). This suggestion is supported, in fact, by the higher correlations noted between income and dwelling unit value and high maximum monthly water consumption as compared to correlations of the same variables for minimum monthly water consumption observed in the 1977 Tulsa City-County Health Department study previously sited. The Tulsa study correlated low, average, and high month water consumption rates per dwelling unit with median dwelling unit value and median income. Although better correlations were confirmed between high month consumption and the income variables as compared to correlations of these variables with low month consumption, the correlations for the latter were still strong (r = .80 for income, r = .786 for dwelling unit value) supporting the suggestion that household wastewater flows are related to income. The Tulsa study included water consumption during the months of June through November, 1975, which, in all probability, do not include the lowest water consumption months (normally January through March).

The Helms and Vallery, University of Alabama studies(22), aimed at developing a water use predictive model, found the most important determinants of consumption to be the number of dwelling unit occupants and income, with age being of some importance. This study differentiated between retired and nonretired homeowners in the lower income brackets since retirement income was thought to understate the real income of retired persons, in many cases. The study included all months of the year, but separated winter from summer use. Winter months were defined as November through March to differentiate between irrigation and nonirrigation season water uses. In differentiating by family income, this study found per capita winter use by income category to be as follows: less than $6,000, nonretired, 53 gpcd; less than

$6,000, retired, 66 gpcd; $6,000-$10,000, nonretired, 58 gpcd; $6,000-10,000, retired, 68 gpcd; $10,000-$20,000, 58 gpcd; $20,000-$30,000, 70 gpcd; $30,000-$40,000, 62 gpcd; and $40,000 +, 95 gpcd. The phenonemon of water use increasing directly with increasing income during the winter months is evident in these data and supports the premise that the use of outside water for irrigation purposes, etc., is not the only water use activity explaining increased water use among higher socioeconomic groups. The implication for increased wastewater flow as a result of water consumption increasing with income is apparent.

Of the physical water system variables which potentially influence water demand, distribution system line pressure is perhaps the most important. L. Douglas James and Robert R. Lee(25) observed that increases in consumption vary directly with standards of living and the pressure maintained in distribution lines. The relationship between distribution system pressure and flow is direct, that is, flow from typical household fixtures (faucets, showers, etc.) increases directly with water pressure. Howell Moses(26) has observed that pressure may vary from 15 psig to 125 psig but most systems range from between 25 psig and 75 psig. Field observations in the Tulsa area indicate line pressures vary significantly and tend to be lower in some areas of rural water districts where supply lines are longer and smaller in diameter than in urban systems.

Not all of water system pressure variance impacts wastewater flows since the majority of household wastewater flows (see subsequent discussions of household water consumption by category) are from constant volume devices for which consumption rates are not directly affected by distribution system pressure. These include toilets, automatic dishwashers, and washing machines. Water uses at sinks, garbage disposers, bathtubs and shower facilities are, however, directly affected by distribution system pressure. One of the more detailed studies of wastewater variation, in terms of hourly water use patterns, was conducted during the early 1970's by Edwin Bennett, et al.(27). Although the distribution of water use by appliance and/or activity category varies significantly among studies, the findings of Bennett indicated only thirty-eight percent of household wastewater uses would be likely to be affected by distribution system pressure.

Numerous authors have reported average household water use including: Murawczyk and Ihrig(28)-246 gpd; LindaWeaver, Geyer and Wolff(29)-247 gpd; Reid(30)-233 gpd, and Bailey, et al.(31)-255 gpd. The average waste flow figure specified for a three-bedroom lagoon design in Oklahoma(1) is 263 gpd. James and Lee(25) report normal ranges of residential consumption to be between seventy and ninety gpcd while average daily urban water use in the United States is 140 gpcd. The 1977 Tulsa City-County Health Department study found average residential water consumption varied from 124 gpd to 461 gpd among the thirteen study areas examined. Per capita consumption rates varied from 38 gpcd to 144 gpcd for these areas(10). Since the reported household water consumption figures represent average water consumption, they cannot be expected to provide an accurate representation of wastewater flows which are best based upon consumption during winter months when near 100% return flows to sewers occur. The 1977 study by the Tulsa

City-County Health Department found average residential water consumption varied from 124 gpd to 461 gpd among the thirteen study areas examined(13).

The Helms and Vallery study(22) concluded that the dominant factor, in addition to age and income, in determining water consumption is the number of occupants per dwelling unit. Analysis of data collected during their surveys determined the median winter daily per capita water use for households of different populations to be as follows: One person-84 gpcd, Two persons-65 gpcd, Three persons-61 gpcd, Four persons-53 gpcd, Five persons-44 gpcd, and Six persons-41 gpcd. It is obvious from these data that water consumption, while increasing for the household in total with each additional member, decreases on a per capita basis with each additional member. The average daily per capita rates of consumption reported by Helms and Vallery is reasonably consistent with similar per capita flows reported by Zanoni and Rutkowski(32) for a study area near Milwaukee, Wisconsin, and others reported by Ligman, et al.(33), as well as the average per capita waste flow figure determined during this study which was 63.5 gpcd.

These average water consumption levels, however, are somewhat less than the commonly used seventy-five gpcd figure often employed as the standard flow for sizing onsite (septic tank) individual sewage disposal systems. Eric H. Bartcsh, Director of the Division of Water Programs for the Virginia Department of Health, compiled several parameters pertaining to onsite sewage disposal regulations from most states of the United States in a 1982 survey(34). Of the forty-two states responding to the survey which utilize per capita flow rates in sizing system (some states rely upon numbers of bedrooms for system sizing) twenty-seven used the seventy-five gpcd figure. Other per capita flow rates used included: 50 gpcd, two states; 60 gpcd, one state; 100 gpcd, eight states; 110 gpcd, one state; 125 gpcd, two states, and 150 gpcd, one state.

Although it is recognized that these per capita design figures are inflated to include a safety factor for unusually high per capita flow rates, both the per capita design criteria, the average per capita figure determined during this research, and those previously reported by several of the other studies previously mentioned are significantly greater than values presented in the EPA design manual, Onsite Wastewater Treatment and Disposal Systems(3). This manual reports the average daily wastewater flow from the typical residential dwelling to be approximately forty-five gpcd and typically no more than sixty to seventy-five gpcd. The manual lists the primary influences affecting flow variations as characteristics of plumbing fixtures and appliances and their frequency of use, as well as characteristics of the residing family including number of members, age, and socioeconomic status, as well as geographic location and method of water supply and wastewater disposal.

In developing the forty-five gpcd figure, the manual reviews the results of nine previous studies of residential wastewater characteristics. The results of these studies, compared with similar results from this research, are summarized in Table 4.2. The average per capita wastewater flow for each of the nine studies ranged from thirty-six gpcd to fifty-three gpcd with a weighted average (by number

### TABLE 4.2

### SUMMARY OF REPORTED[1] RESIDENTIAL WASTEWATER FLOWS COMPARED WITH TULSA AREA SURVEY RESULTS

| SOURCE | NO. OF DWELLING UNITS | DURATION OF STUDY (mo.) | STUDY AVG. FLOW (gpcd) | RANGE OF DWELLING UNIT UNIT FLOWS(gpcd) |
|---|---|---|---|---|
| Linaweaver, et al. (29) | 22 | - | 49 | 36-66 |
| Anderson and Watson (35) | 18 | 4 | 44 | 18-69 |
| Watson, et al(36) | 3 | 2-12 | 53 | 25-65 |
| Cohen and Wallman (37) | 8 | 6 | 52 | 37.8-101.6 |
| Laak (38) | 5 | 24 | 41.4 | 26.3-65.4 |
| Bennett and Linstedt (39) | 5 | 0.5 | 44.5 | 31.8-82.5 |
| Siegrist, et al. (40) | 11 | 1 | 42.6 | 25.4-56.9 |
| Otis (41) | 21 | 12 | 36 | 8-71 |
| Duffy, et al (42) | 16 | 12 | 42.3 | - |
| Tulsa Study | 34 | 2 | 63.5 | 25-120 |

[1] Literature Summary reported by (3)

of residences) of forty-four gpcd. Individual residential flow rates during these studies ranged from as little as 8 gpcd to as much as 101.6 gpcd. By comparison, Tulsa area consumption rates determined during this study, which included thirty-four residences, averaged nearly twenty gpcd (approximately forty-four percent) higher than the average of the previous nine studies and also higher than the average flow rate for any of the individual studies.

Several studies of wastewater flows and household water consumption have provided percentage breakdowns of water use by category and/or activity. Some of these have been summarized in Table 4.3 which delineates consumption by the major categories of toilet use, bathing, laundry, and "other". The Helms and Vallery, University of Alabama study(22), relied upon regression analysis to explain variances in household water use as it related to the number and age of occupants and to appliances. They determined the presence of automatic dishwashers to be the only variable which was not significant, i.e., the presence of a dishwasher in the household did not provide additional information relating to the water use characteristics of the house. This is probably due to the relatively small water consumption of dishwashers coupled with the fact that hand dishwashing may consume a nearly equivalent quantity of water.

The EPA onsite system design manual(3), reports dishwashers consume an average of 8.8 gallons per use while garbage grinders consume an average of approximately two gallons per use based upon data concerning residential water use by activity compiled from five separate studies. The combined effects of water consumption for both of these

TABLE 4.3

PERCENTAGE OF REPORTED HOUSEHOLD WATER CONSUMPTION BY CATEGORY OF USE

| USE CATEGORY | | | | SOURCE |
|---|---|---|---|---|
| TOILET | BATHING | LAUNDRY | OTHER | |
| 33.0 | 20.0 | 26.1 | 21.3 | Bennett, et al.(27) |
| 27-45 | 18-36 | 18 | 19 | Bostian(43) |
| 39 | 31 | 17 | 13 | McLaughlin(44) |
| 39.2 | 31.4 | 13.7 | 15.7 | Compilation(45) |
| 41.2 | 34.3 | 14.6 | 9.9 | Reid(46) |
| 38 | 34 | 12 | 16 | Besik(47) |
| 22 | 23 | 25 | 30 | Siegrist, et al.(48) |
| 47 | 21 | 18 | 14 | Laak(38) |
| 41 | 26 | 19 | 14 | Ligman(49) |
| 27[1] | 35 | 21 | 17[2] | This Study |

[1] "Toilet" use estimated from other reported uses/cap/day, see text.

[2] "Other" use was determined as the residual.

appliances, relative to other household water consumption, is small and the influence of their use could be easily masked by variances in other water consumption activities. Interestingly, however, the Helms and Vallery study, which found no explanatory value in the presence of automatic dishwashers in households, determined (by using multiple regression techniques) that the presence of garbage disposers contributes an additional 787 gallons per month to household water use. In view of the small water consumption of this appliance, the authors explained this excessive use as a reflection of the surrogate relationship of the use of this appliance to income and lifestyle. This study determined that the use of automatic clothes washing machines in Tulsa area Households contributes an additional 643 gallons per month, on the average, to the wastewater flow of the surveyed dwelling units.

## Wastewater Flow Analysis

Data were collected during the course of this research to assess the impact of distribution system pressures on wastewater flow variance. Static water pressure readings were taken at outside hydrants at each residence during site visits, for a total of three pressure readings (in most cases) for each of the thirty-six dwelling units. Pressures varied considerably among housing units ranging from a minimum pressure of 36 psig to a maximum of 120 psig. All of the systems studied were served by public water supplies, most by rural water districts. Mean water pressure for all of the dwelling units was 73.8 psig with a standard deviation of 22.8 psig. While substantial variance was observed in pressures among units, pressures at the same unit rarely varied more than five psig between visits.

The water pressure data were subjected to statistical analysis utilizing both analysis of variance and regression analysis. Analysis of variance failed to confirm a statistically significant differences in per capita consumptions both when the data were divided into two groups (dwelling units with pressures less than or equal to seventy psig as compared with dwelling units with pressures greater than seventy psig) and among three pressure groups (less than sixty psig, sixty to eighty psig, and greater than eighty psig). Linear regression analysis resulted in a very poor correlation between static water pressure and per capita water consumption (r = .07) and the slope of the regression line was not statistically significant (F ratio = .14) confirming that the linear regression model offered no improvement in predictive capability beyond the use of simple mean per capita consumption figures for all water pressures.

Water pressure data were also included in multiple regressions along with household physical and activity variables such as numbers of occupants, numbers of bathrooms, occupant ages, numbers of rooms, baths and showers taken per day, laundry loads washed per day, etc., in attempts to better predict household water consumption. Due to the poor correlation of household consumption with water pressure relative to other variables, pressure was selected as one of the last variables in step-wise multiple regression runs. A plot of average static water pressure versus average daily per capita water consumption for the dwelling units included in the study is shown in Figure 4.7. The lack of correlation between these two variables is obvious in that figure.

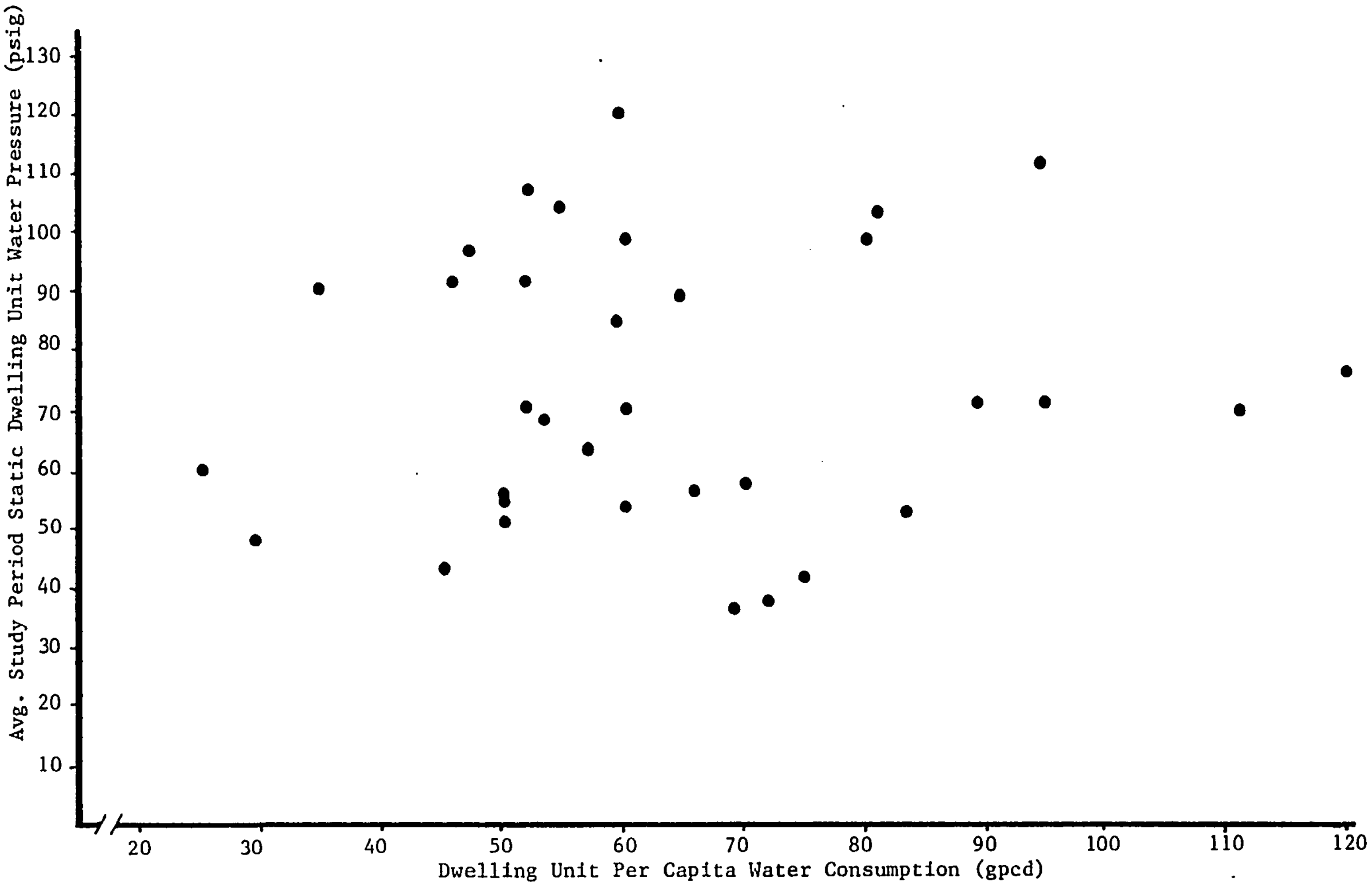


Figure 4.7 Average Static Water Pressure versus Average Daily Per Capita Water Consumption of Surveyed Dwelling Units During Study Period

The poor correlation between system static water pressure and per capita water consumption is probably the result of the relatively minor influence of this variable relative to the variances of the more highly correlated variables. This is likely due, in part, to the small sample size as well as the fact that only approximately thirty-eight percent of household water use is subject to the effects of pressure.

It was not possible to examine dwelling unit water consumption by income category since an income question was not specifically included in the household questionaire due to the sensitivity of respondents to such questions. However, approximate measures of income were included in the form of two questions pertaining to dwelling unit value and square footage. Responses to the former question were limited, necessitating estimates of current (1983) dwelling unit value from available data. The estimated current value was, not surprisingly, highly correlated with dwelling unit square footage ($r = .97$) since the development of the housing unit value was based, in part, on dwelling unit square footage. Regression analysis of dwelling unit average daily water consumption and dwelling unit square footage indicated a statistically significant (.95 confidence level) direct correlation between these two variables although the correlation coefficient value ($r = .39$) suggested that house square footage was capable of explaining only approximately fifteen percent of household water consumption variance. A plot of average daily water consumption versus dwelling unit square footage is presented as Figure 4.8. Correlation analysis of dwelling unit square footage versus per capita water consumption did not indicate a statistically significant relationship, however, due

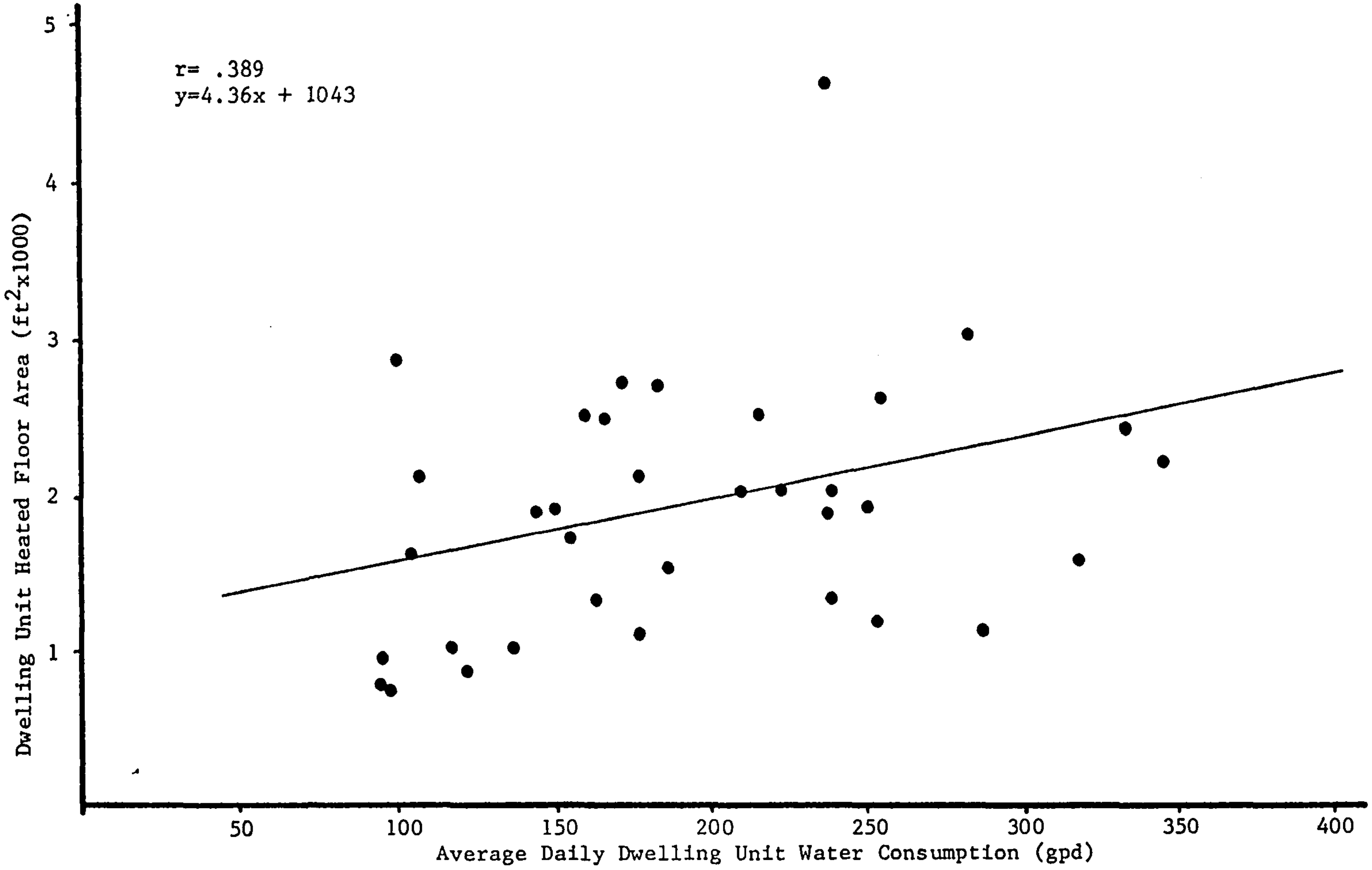


Figure 4.8 Surveyed Dwelling Unit Heated Floor Area versus Average Daily Study Period Water Consumption

apparently to a few unusually high per capita consumption rates in dwelling units of smaller square footages.

Variations in the influence of income on household wastewater flows, as reflected by wintertime water consumption, may be partly related to higher percentages of water-using appliances such as clothes washers, dishwashers and garbage disposers in higher income households. Such fixtures as toilets, tubs or showers, and sinks are present in virtually all residences. Because of the relatively rural nature of most households for which individual lagoons are designed, and their relative inaccessibility to commercial laundry facilities, automatic clothes washers may be presumed to be present in nearly all of these households (only one of the thirty-six dwelling units included in this study did not contain a clothes washer). The impact of differential appliance and fixture use on wastewater flows, therefore, is essentially limited to dishwashers and garbage disposers which have comparatively small consumption rates per use.

The average daily household water consumption for dwelling units included in this study was 190 gpd, ranging from 92 gpd to 342 gpd. Per capita water consumption ranged from 25 gpcd to 120 gpcd, averaging 63.5 gpcd. An estimated categorical breakdown of this use, in terms of toilet use, bathing, laundry, and "other", was presented in Table 4.3 along with reported categorical water consumption from other studies. The percentages of water consumption for this study shown in that table were estimated from questionaire reporting of bathing, clothes washing and dishwashing uses per capita per day as applied against the mean gallons per use figures reported in the EPA onsite system design manual(3) data presented in Figure 4.4. Information pertaining to garbage grinding, toilet flushing, and miscellaneous uses were not acquired during the survey of the studied households. These data were, therefore, assumed to be equivalent to the mean data presented for these categorical uses by the other studies for which data were reported in Table 4.4. Percentages of water use reported in the studies, shown in Table 4.3, ranged from 20 to 47 percent for toilet use, 18 to 36 percent for bathing, 12 to 26.1 percent for laundry and 9.9 to 30 percent for the miscellaneous or "other" category. The results of the estimates for households participating in this study show toilet use to be on the low end of the range reported by the other studies while bathing use was on the high end of the range reported by others. Consumption for the laundry and the "other" category were relatively average compared to the others.

As previously discussed, the average daily per capita water consumption determined for the dwelling units included in this research was, at 63.5 gpcd, significantly higher than the average of per capita wastewater flows for the nine studies reviewed in the EPA onsite system design manual(3) (see Table 4.2). The explanation for this higher per capita waste flow rate in the metropolitan Tulsa study area may be largely explained by the relatively high percentage of one- and two-person households included in the study( 41.2 percent) which, in the Helms and Vallery water consumption studies(22), exhibit a comparatively high per capita water consumption. Both the Helms and Vallery studies and subsequent multiple regression analysis of these survey data, relating water use to household age categories (discussed in subsequent

## TABLE 4.4

## SUMMARY OF REPORTED[1] RESIDENTIAL WATER USE BY ACTIVITY COMPARED WITH TULSA AREA SURVEY RESULTS

| | GAL/USE | USES/CAP/DAY | | gpcd | |
|---|---|---|---|---|---|
| ACTIVITY | | Literature | Tulsa | Literature | Tulsa |
| Toilet Flushing | 4.3<br>(4.0-5.0) | 3.5<br>(2.3-4.1) | (n.d.)[2] | 16.2<br>(9.2-20.0) | 16.2[3] |
| Bathing | 24.5<br>(21.4-27.2) | 0.43<br>(0.32-0.50) | .84<br>(0.14-1.43) | 9.2<br>(6.3-12.5) | 20.6 |
| Clothes-washing | 37.4<br>(33.5-40.0) | 0.29<br>(0.25-0.31) | .33<br>(0.07-0.67) | 10.0<br>(7.4-11.6) | 12.3 |
| Dish-washing | 8.8<br>(7.0-12.5) | 0.35<br>(0.15-0.50) | .27<br>(0.07-1.07) | 3.2<br>(1.1-4.9) | 2.4 |
| Garbage Grinding | 2.0<br>(2.0-2.1) | 0.58<br>(0.4-0.75) | (n.d.)[2] | 1.2<br>(0.8-1.5) | 1.2 |
| Misc. | - | - | - | 6.6<br>(5.7-8.0) | 6.6[3] |
| Total | - | - | - | 45.6<br>(41.4-52.0) | 59.3[4] |

[1] Mean and Ranges of results reported by (33)(37)(38)(39)(40) as summarized by (3)

[2] n.d. - not determined

[3] Uses assumed to be equivalent to literature summary average

[4] Per capita use determined directly from survey data: mean= 63.5 gpcd, range= 25-111 gpcd

paragraphs), indicate a significant portion of the greater water use in one- and two-member households is due to the effects of dwelling unit "baseline" consumption.

Table 4.4, which presents residential wastewater flow rates by category or activity, showing the average consumptive uses of six major activities, the range of those uses, the reported uses per capita per day, and the total per capita figure for each activity, is based upon five of the nine studies surveyed in the EPA onsite systems design manual(3). Although, as previously discussed, household survey questions were not included in this research from which per capita toilet flushing and garbage grinding frequencies could be determined, the frequencies of bathing, clothes washing and dishwashing were requested. Utilizing these survey responses, data from this study could be compiled in a manner similar to that of the other five studies reported in Table 4.4 (toilet flushing, garbage grinding and miscellaneous were assumed to be equivelent to the average of the other five studies) and estimates of per capita waste flows by activity could be deduced for the Tulsa data. Interestingly, when the per capita waste flows by activity were totalled utilizing this technique, the overall gpcd figure was 59.3 which agrees favorably with the 63.5 gpcd average figure previously determined. This finding additionally supports the legitimacy of the higher per capita waste flow figure determined for the Tulsa area relative to the 45.6 gpcd value of the previous studies developed using this same method. This comparison suggests that differences in Tulsa area per capita consumption by activity compared to the previous studies lie in increased per capita use for bathing, and a slightly increased per capita use for clothes washing.

The EPA onsite system design manual(3) presents a frequency distribution of average per capita daily residential wastewater flows based upon all of the seventy-one residences included in seven of the nine studies surveyed for that document. This frequency distribution is reproduced in Figure 4.9 along with a similar frequency distribution of the per capita waste flow figures determined during this study. The distribution shows an approximate twenty gpcd shift in per capita waste flows over the EPA reported flows. The result is a median per capita residential waste flow of approximately sixty gpcd for the Tulsa data as compared with 45 for the other studies. The one standard deviation range of approximately forty-six gpcd to eighty-four gpcd would include about sixty-eight percent of residential per capita waste flows.

Water consuming appliance use frequency in individual households directly affects wastewater flow rates and varies considerably among dwelling units. This variance is evident in the ranges of such uses presented in Table 4.4. The ranges and computed averages of bathing, clothes washing and dishwashing activities, as determined from the household questionaire responses received during this study, are presented in that table for comparison. Despite the variance among households in water use activity frequency, statistically significant direct correlations between numbers of dwelling unit occupants and numbers of water using activities per day were confirmed by statistical analysis. The highest correlation (r=.722) was obtained for number of occupants versus baths and showers taken per week (baths/showers = 5.367 (No.Occ.)+1.577) with a weaker correlation (r=.696) shown for number of

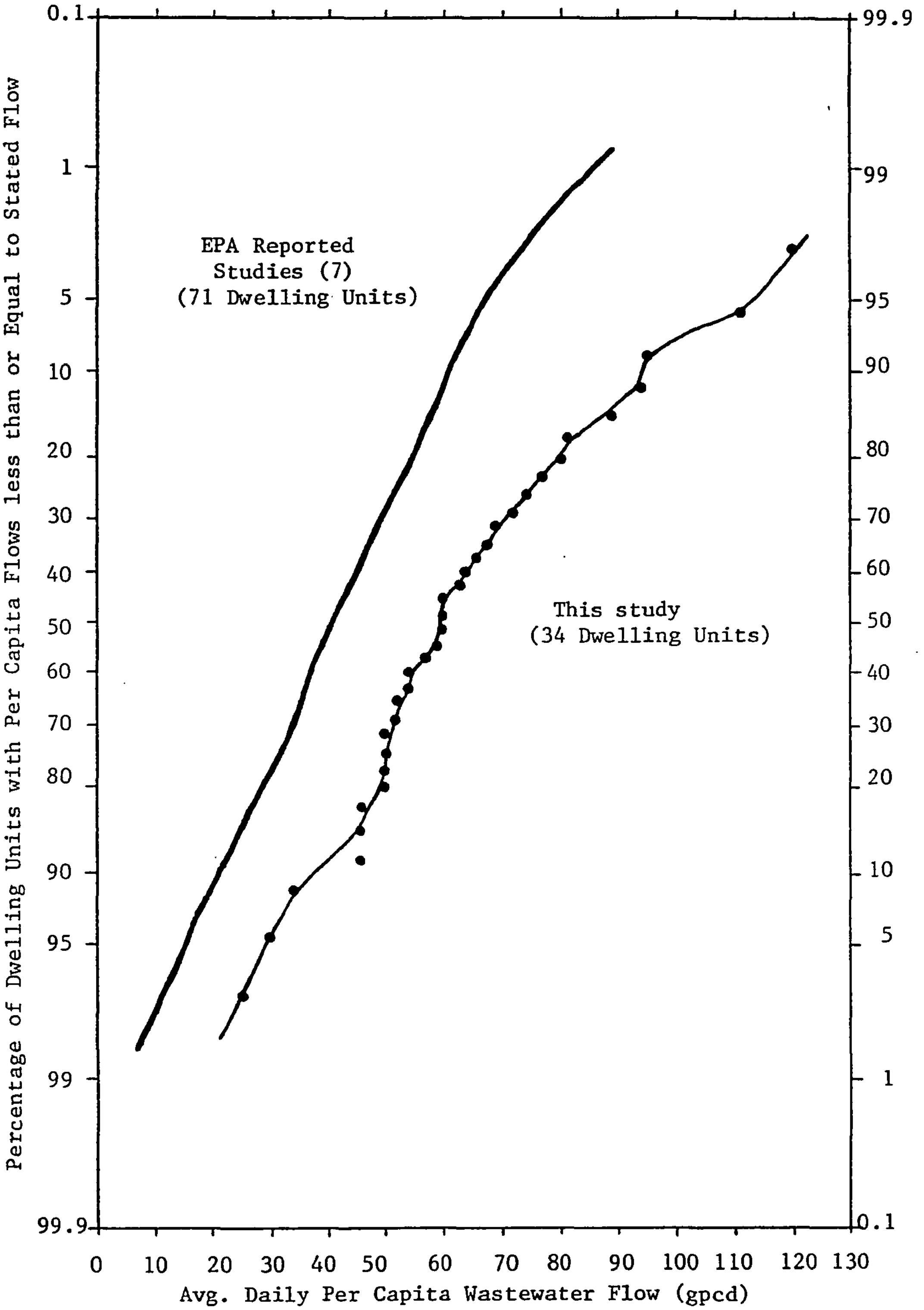


Figure 4.9 Frequency Distributions of Average Daily Per Capita Wastewater Flows Reported in Previous Studies and those Determined for Tulsa Area Surveyed Dwelling Units

occupants versus loads of laundry (r = .696). The correlation between numbers of occupants and loads of dishes washed per week was very weak and the slope of the resulting regression line not significant. The former two regressions were statistically significant at levels of confidence greater than .999. Plots of these relationships are presented as Figures 4.10, 4.11 and 4.12.

The University of Alabama water consumption studies by Helms and Vallery(22) examined the importance of age and the number of children in the household as predictors of water use. As previously mentioned, age, number of children, and types of water using appliances were found to explain about thirty-five percent of total variance in water use during that study by applying multiple regression analysis. Preteenage children in the family were each indicated to consume about 269 gallons per month, teenagers each utilized an average of approximately 1,102 gallons per month, and adults were reponsible for about 813 gallons per month each in wintertime water consumption. The analysis indicated that water use declined as the head of the household aged, a trend that was found to slow somewhat in retirement years.

The Tulsa area study data were subjected to analysis of variance comparing households with and without children as well as to multiple regression analysis similar to that employed by Helms and Vallery. For the analysis variance examination, children were defined as household occupants less than twenty years of age. Analysis of variance determined that per capita wastewater flow (wintertime water consumption) for households without children averaged 71.8 gpcd as compared with an average per capita flow of 51.8 gpcd from households

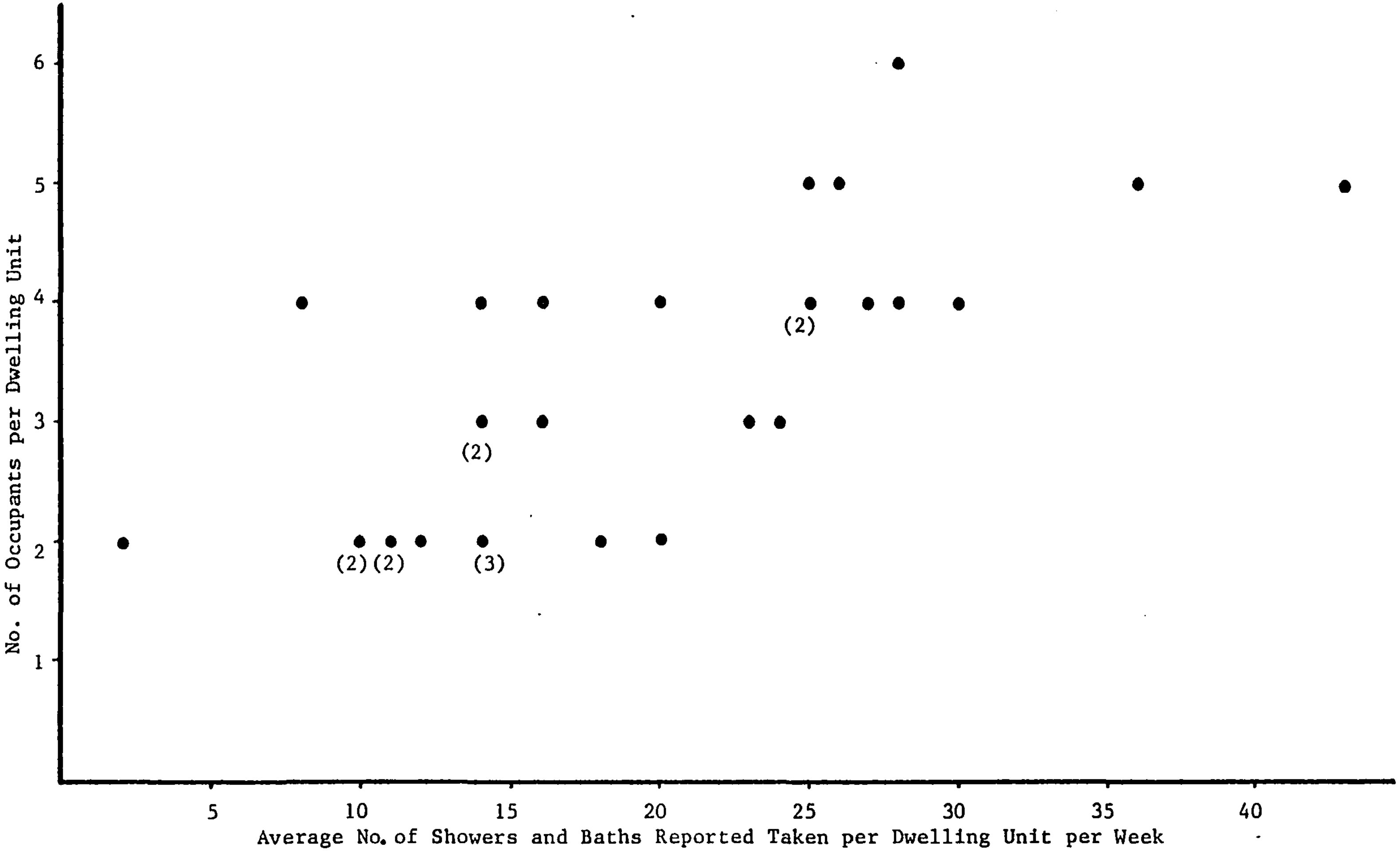


Figure 4.10 Number of Dwelling Unit Occupants versus Reported Average Number of Showers and Baths Taken per Dwelling Unit per Week

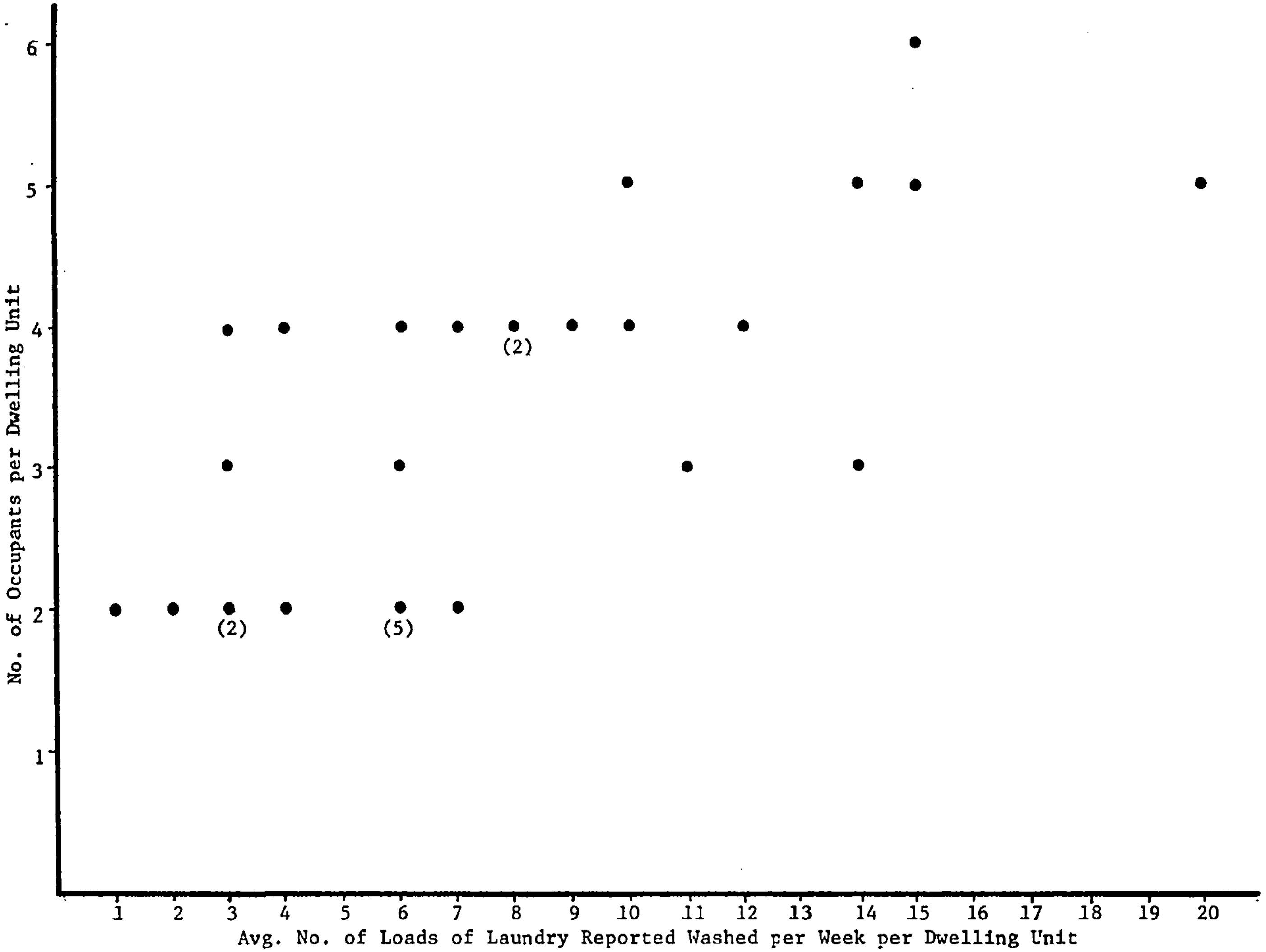


Figure 4.11 Number of Dwelling Unit Occupants Versus Reported Avg. No. of Loads of Laundry per Dwelling Unit per Week

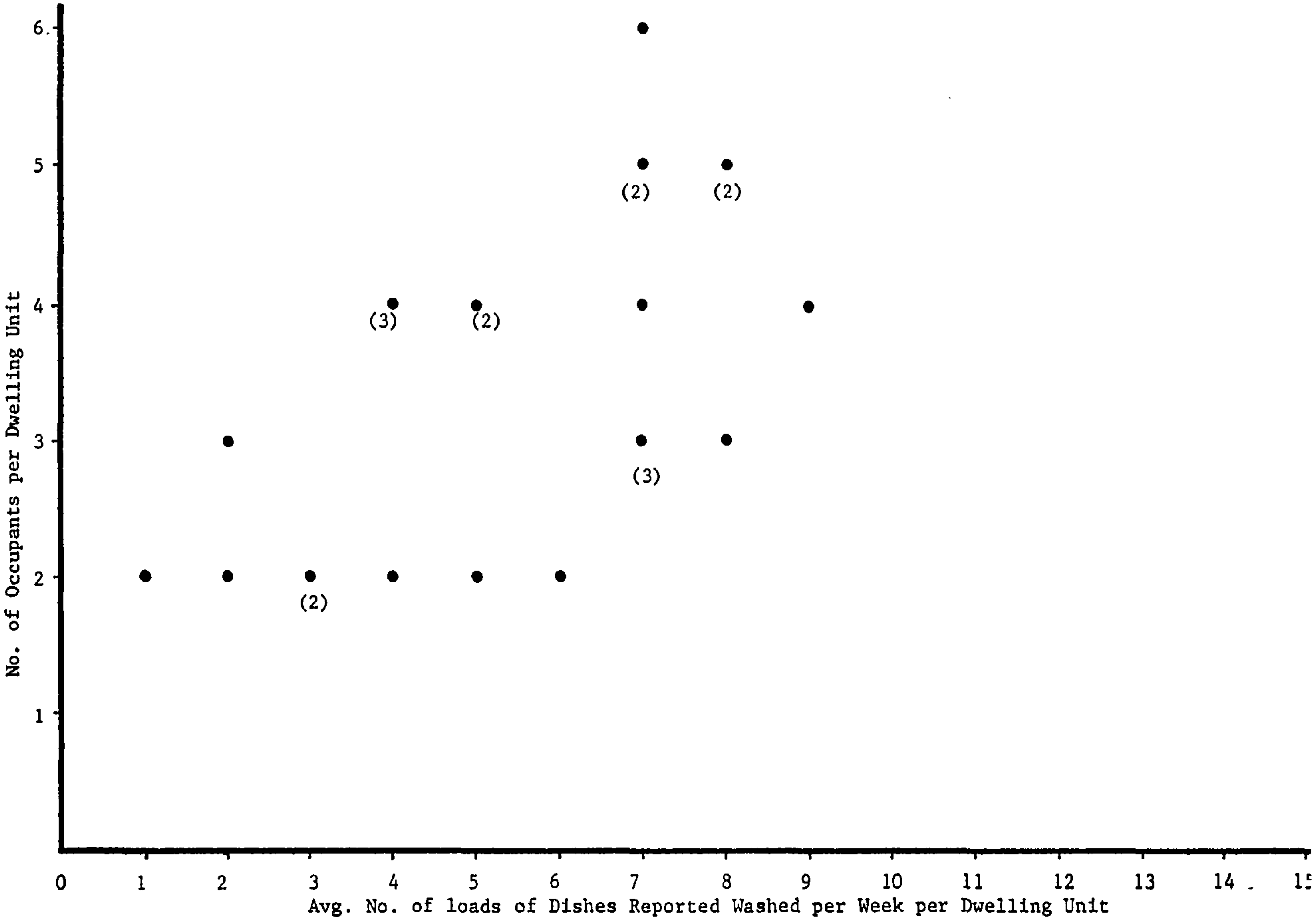
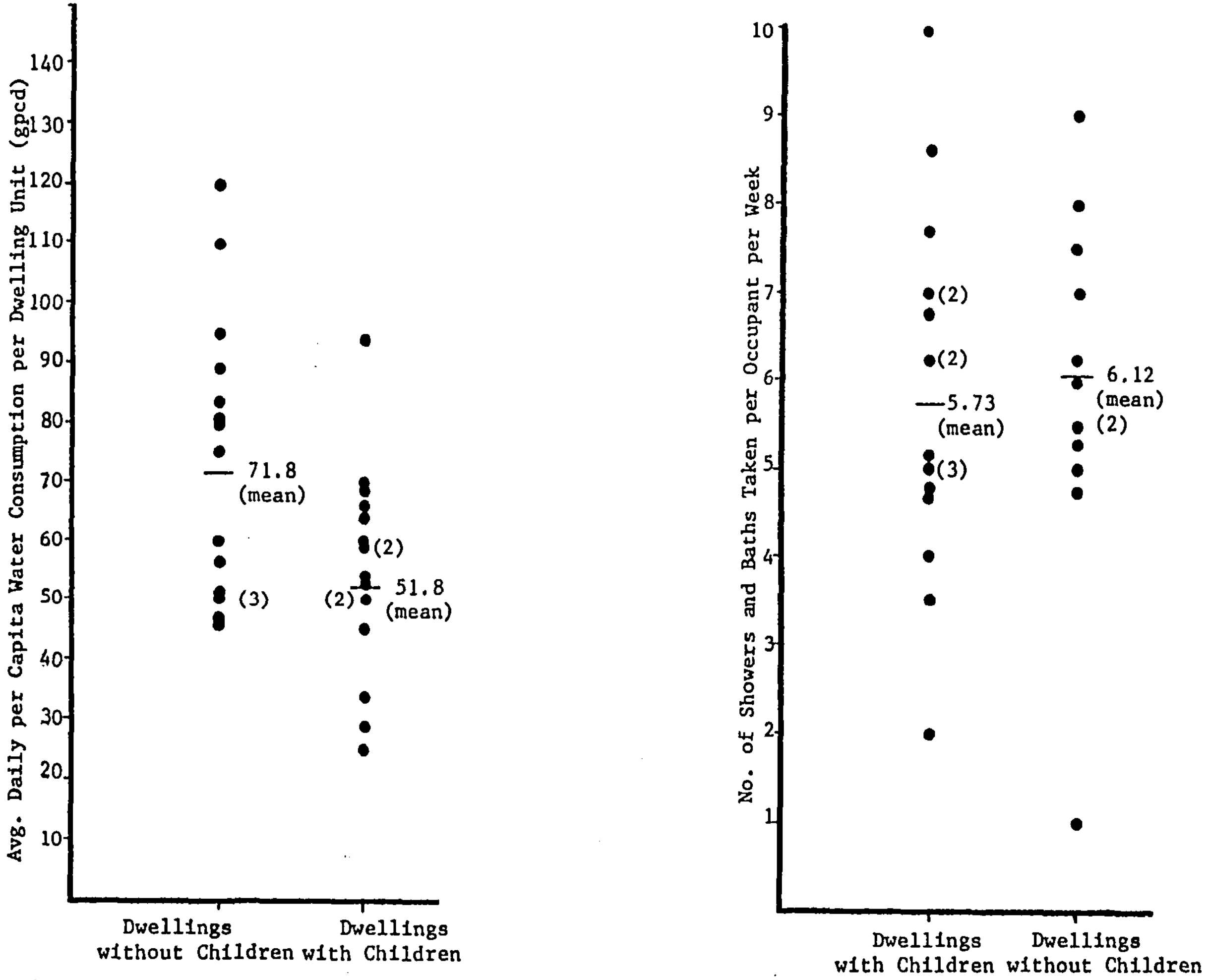


Figure 4.12 Number of Dwelling Unit Occupants Versus Reported Average Number of Loads of Dishes Washed per Dwelling Unit per Week

with children, a twenty gpcd differential, which is partially due to a "baseline" household water use discussed in subsequent paragraphs. This result was statistically significant at the .995 level of confidence. It is important to note that all but one of the households without children were two-member households (one was a one-member household). The majority of the two-member households were comprised of individuals less than retirement age but of sufficent age that their children, if any, would have left home. In only one of the two-member households were both members of retirement age. For this reason, a differential analysis of retirement age households versus preretirement age households without children was not possible due to data limitations.

Additional analysis comparing the water consuming appliance use rates of households with and without children was also completed for baths and showers taken per week, loads of laundry washed per week and loads of dishes washed per week (for households utilizing automatic dishwashers). This analysis indicated slight differences in use rates between the two groups, although none proved to be statistically significant in subsequent analysis of variance comparisons. Graphical presentations of the comparative distributions of per capita water consumption and water use activities for households with and without children may be found in Figure 4.13.

Multiple regression analysis, relating dwelling unit wastewater flows to numbers of dwelling unit occupants differentiated by age category, produced valuable results for predictive modeling. The age categories utilized for this analysis grouped occupants into three categories: Children ages newborn through nine years, children ages nine



(Note: Numbers in parentheses denote common plots; Children are defined as being less than 20 yrs)

Figure 4.13a Average Daily per Capita Water Consumption and Average Number of Showers and Baths Taken per Occupant per Week for Dwelling Units with Children Versus Units without Children

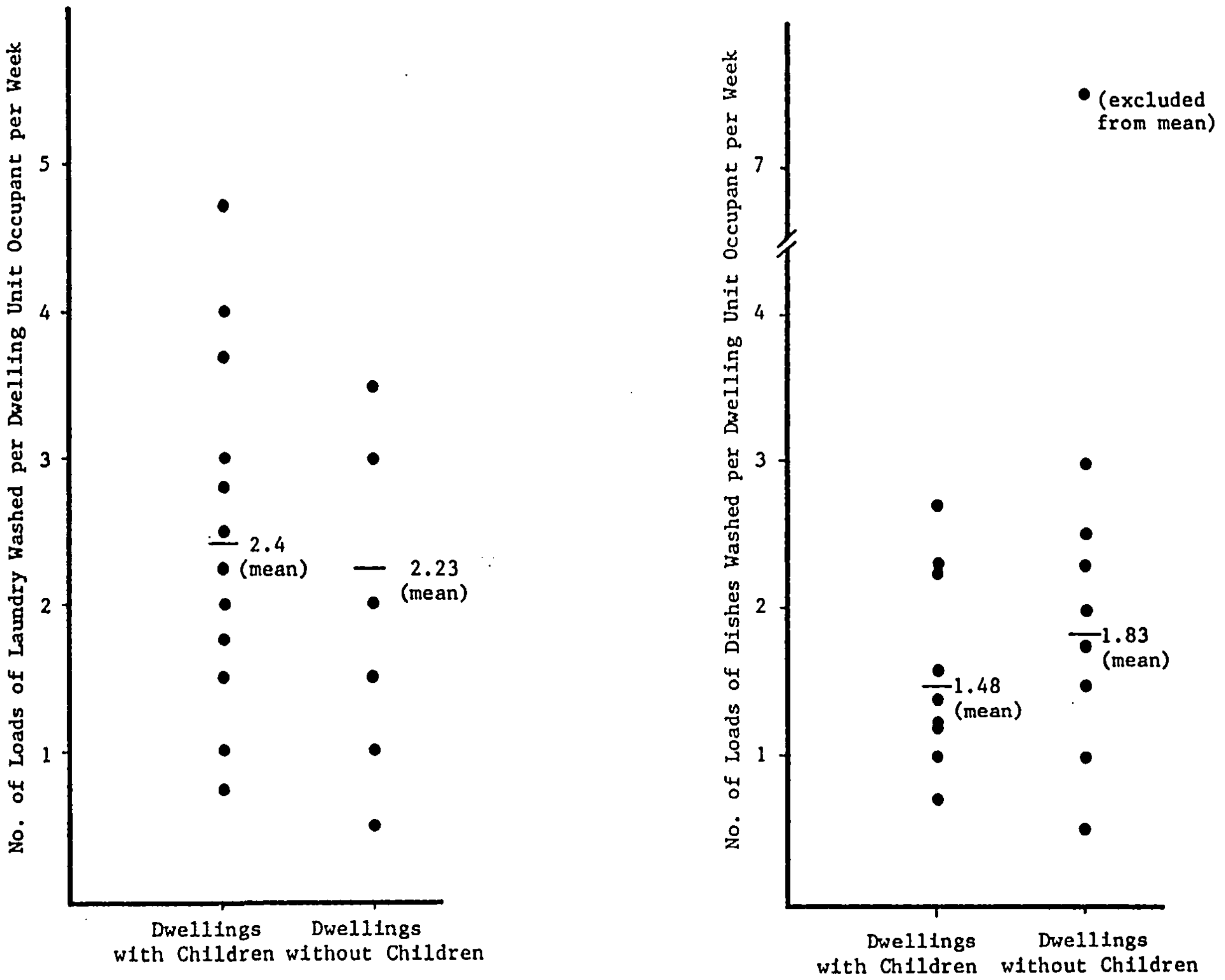


Figure 4.13b Average Number of Loads of Laundry and Dishes Washed per Dwelling Unit per Week for Dwelling Units with Children Versus Units without Children

through nineteen years, and adults greater than twenty years of age. The resulting regression produced a good multiple correlation coefficient(r = .796) indicating the age groupings were capable of explaining more than sixty-three percent of the variance in dwelling unit water consumption. The corresponding equation, which was statistically significant at greater than the .999 level of confidence, is presented below:

$$\text{Dwelling Unit Water Consumption (gpd)} = 23.7x_1 + 63.86x_2 + 26.1x_3 + 88.6$$

Where:

$x_1$ = no. children 0-9 yrs.
$x_2$ = no. children 10-19 yrs.
$x_3$ = no. adults (20 yrs. +)

The equation coefficients suggest that children ages nine and under, and adults, are responsible for roughly equivalent average daily water use at 23.7 and 26.1 gpcd, respectively, while older children are responsible for well over twice this use at 63.9 gpcd. The residual, or error component (intercept) of the equation, which is 88.6 gpd, is substantial and represents what can be considered to be "baseline" household water consumption related to the general operation of the average household without regard to numbers or ages of occupants. It is this "baseline" consumption which is largely responsible for households without children averaging twenty gpcd greater water use than households with children previously noted in the analysis variance comparison.

Of the thirty-six dwelling units included in the residential lagoon survey, twenty-seven were site built houses and seven were mobile homes. In view of the generally smaller size of mobile homes and the fact that families residing in these units normally reflect a lower household income, per capita water consumption rates for the two groups were subjected to analysis of variance to identify any significant consumption differential between the two. The results of that analysis did not confirm a significant difference in consumption rates between the two groups which averaged 64.5 gpcd for site built houses and 59.3 gpcd for mobile homes. The failure to confirm a statistically significant differential in per capita consumption between these two groups could well be due to the small sample of mobile home units included in the analysis relative to the variance exhibited in per capita consumption. Standard deviations of per capita consumption were 24.8 gpcd for mobile homes and 20.4 gpcd for site built houses.

Correlation analysis relating simply numbers of dwelling unit occupants with average daily household water consumption shows these variables to be fairly well correlated ($r = .66$) with this variable alone capable of explaining approximately forty-four percent of household consumption variance. A plot of this relationship is presented as Figure 4.14. By employing multiple regression analysis of the Tulsa data, which included an extensive number of household variables including baths per day, number of occupants, number of bathrooms, laundry loads per day, average age of occupants, number of rooms, average water pressure, number of bedrooms, and house square footage, it was possible to achieve a 69.1 percent explanation of household water

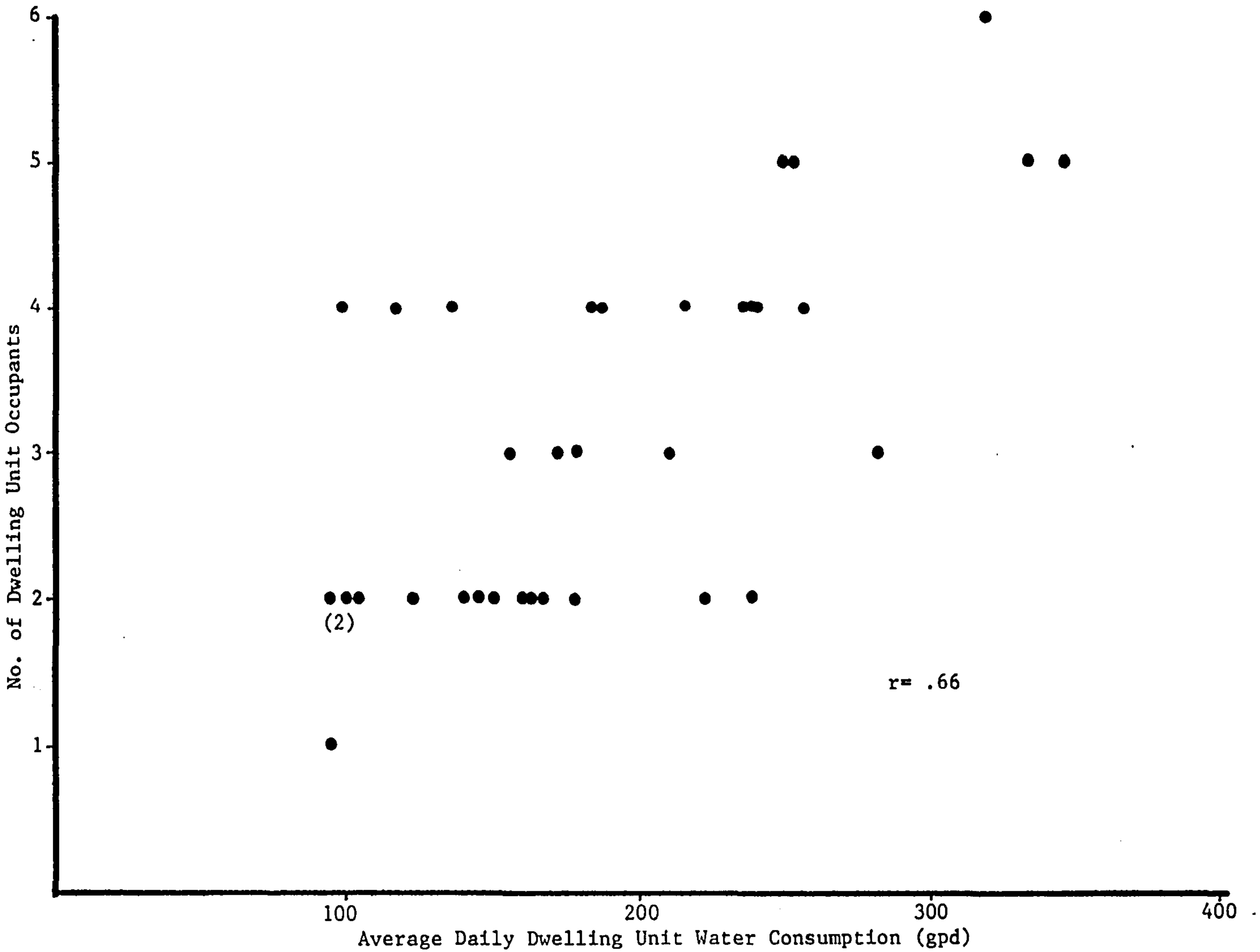


Figure 4.14 Number of Dwelling Unit Occupants Versus Average Daily Dwelling Unit Water Consumption During Study Period

consumption variance (r = .831). However, the use of this many variables in an equation for predicting household water consumption is both cumbersome and impractical. Nearly all of the variance explanation (63.9%) can be achieved by utilizing only the three most highly correlated variables (r=.799) which include number of baths and showers taken per day, number of occupants and number of bathrooms. The resulting multiple regression equation produced by these variables, which is statistically significant at greater than the .999 level of confidence is as follows:

$$\text{Dwelling Unit Water Consumption (gpd)} = 21.0x_1+22.5x_2+25.9x_3+12.9$$

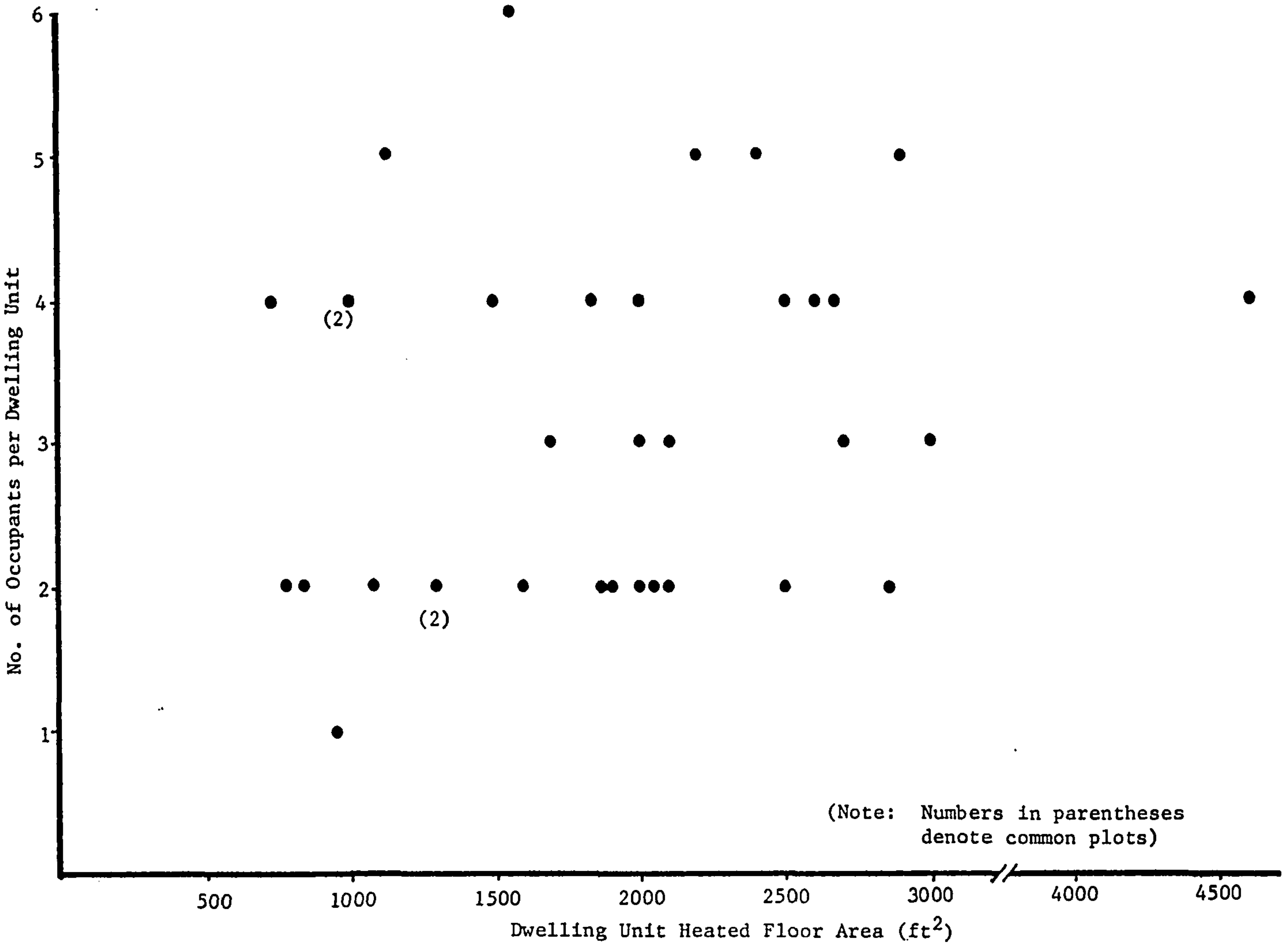
Where:

$x_1$= number of baths and showers taken per day
$x_2$= number of dwelling unit occupants
$x_3$= number of dwelling unit bathrooms

Unfortunately, from the standpoint of designing lagoons on the basis of reliable household wastewater flow predictors, the use of such variables as baths and showers taken per day and number of occupants is of limited usefulness since these variables are subject to substantial change as occupying families change during the design life of the facility. For this reason, it is most desirable for design criteria to be based upon identifiable, physical characteristics of the dwelling unit such as square footage, number of bedrooms, number of bathrooms, dwelling unit value, or predictable demographic or social characteristics for which an identifiable relationship with wastewater flow can be established.

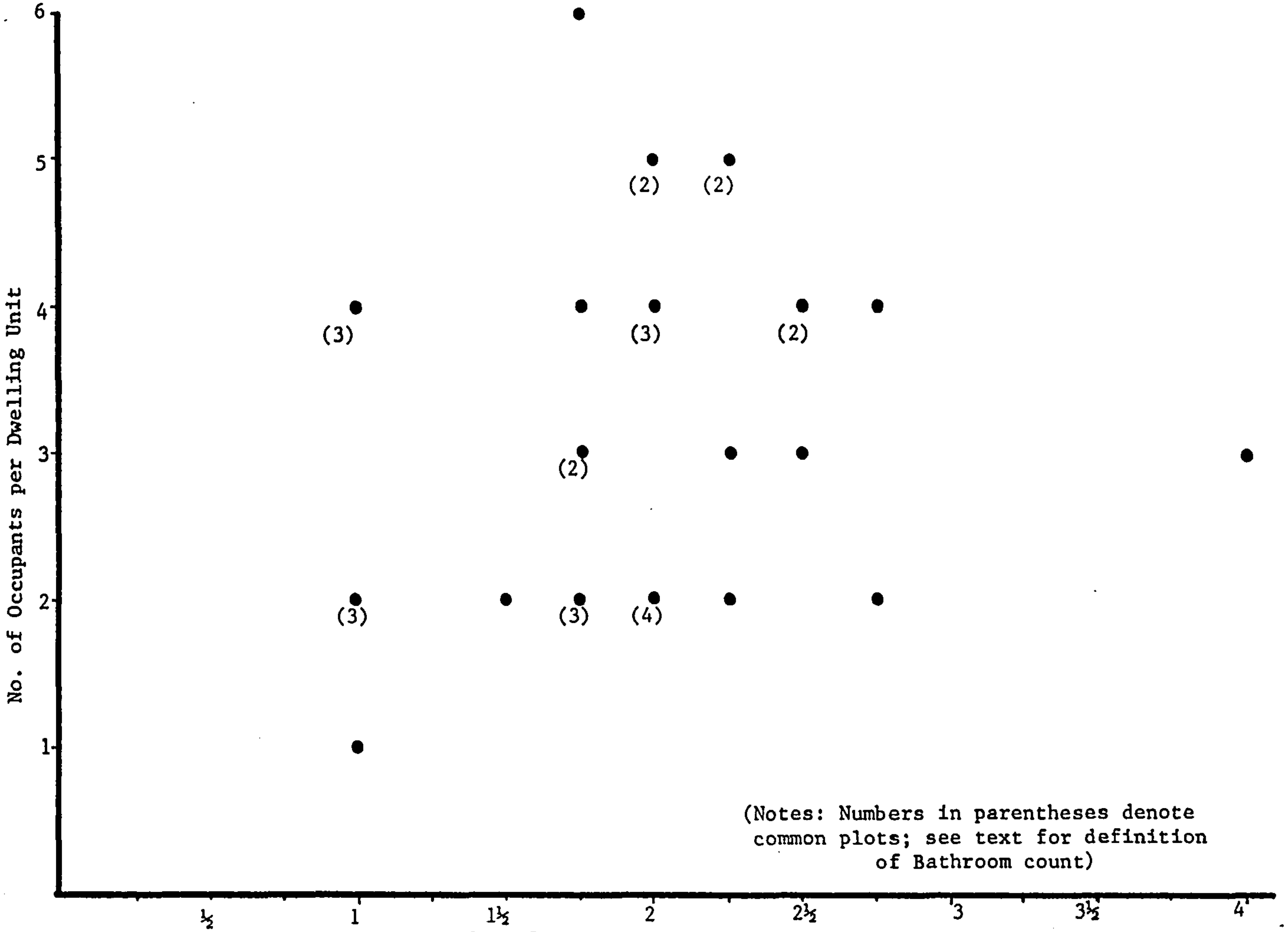
Analysis of the Tulsa area survey data unfortunately failed to indicate useful correlations between numbers of household occupants (which had been identified as the single most important variable capable of explaining the greatest proportion of household wastewater flow variance) and physical characteristics of dwelling units. For example, regression analyses of occupants versus square footage, number of bathrooms and number of bedrooms, all produced poor correlation coefficients and the resulting regression equations, not being statistically significant, failed to provide variance explanations beyond simple use of the mean number of occupants per Tulsa area dwelling unit, regardless of changes in the other variables. Graphical presentations of these relationships are included in Figures 4.15, 4.16, 4.17 and 4.18. This finding is of particular interest since Oklahoma design criteria(1) and the criteria for several other states(34) are based upon numbers of bedrooms which, presumably, bears some relationship to the number of household occupants. In all fairness, however, the use of bedrooms as a basis for design is probably as valid as simply using average per capita daily wastewater flow figures without exploiting additional means of estimating the number of occupants which might be expected to occupy a given dwelling unit.

Neighborhood change analysis, the local examination of which is discussed in a subsequent section of this chapter, was resorted to as a basis for determining more predictable changes in household population



(Note: Numbers in parentheses denote common plots)

Figure 4.15 Number of Occupants per Dwelling Unit versus Reported Dwelling Unit Heated Floor Area



(Notes: Numbers in parentheses denote common plots; see text for definition of Bathroom count)

Figure 4.16 Number of Occupants per Dwelling Unit versus Number of Bathrooms per Dwelling Unit

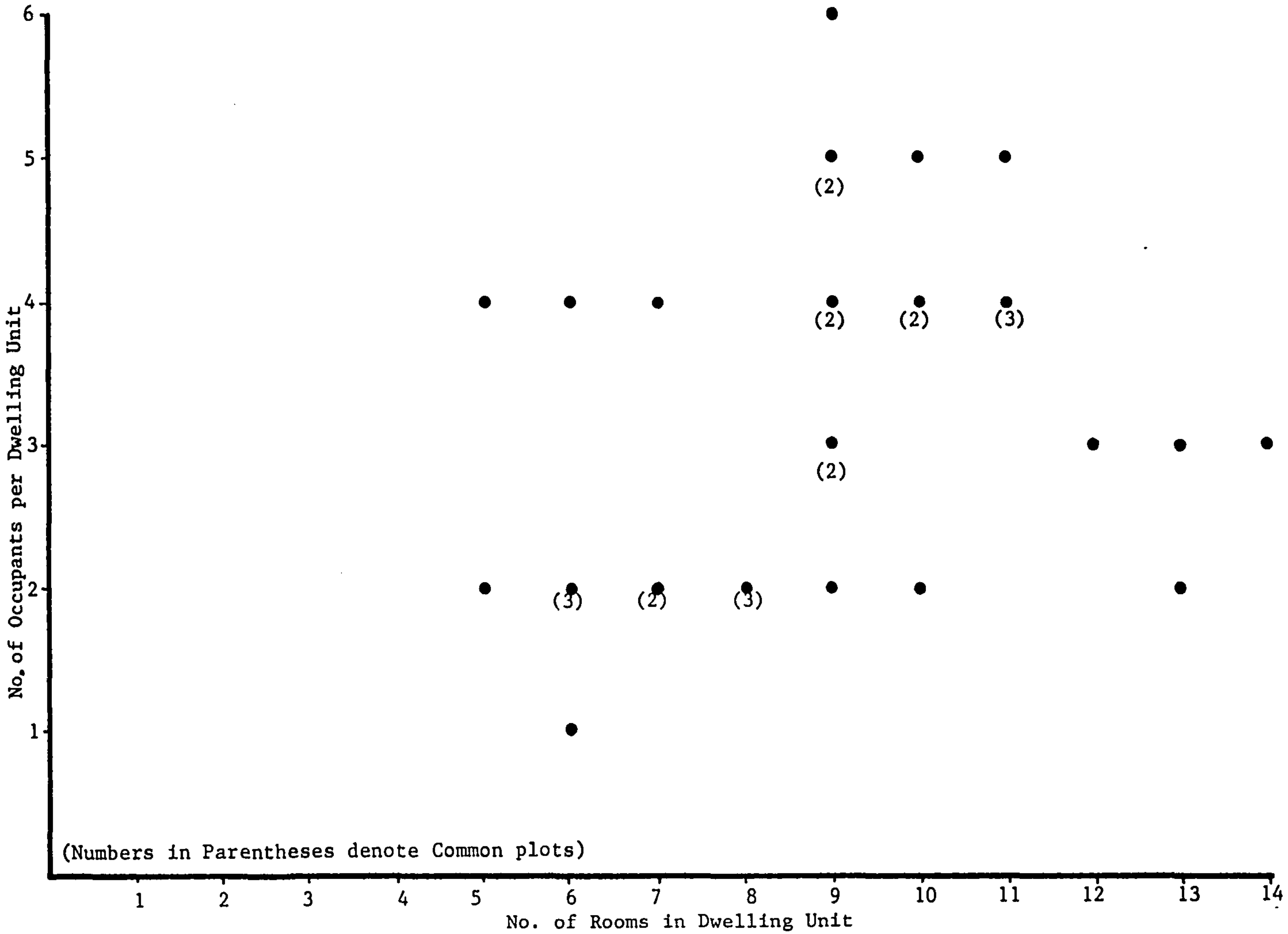
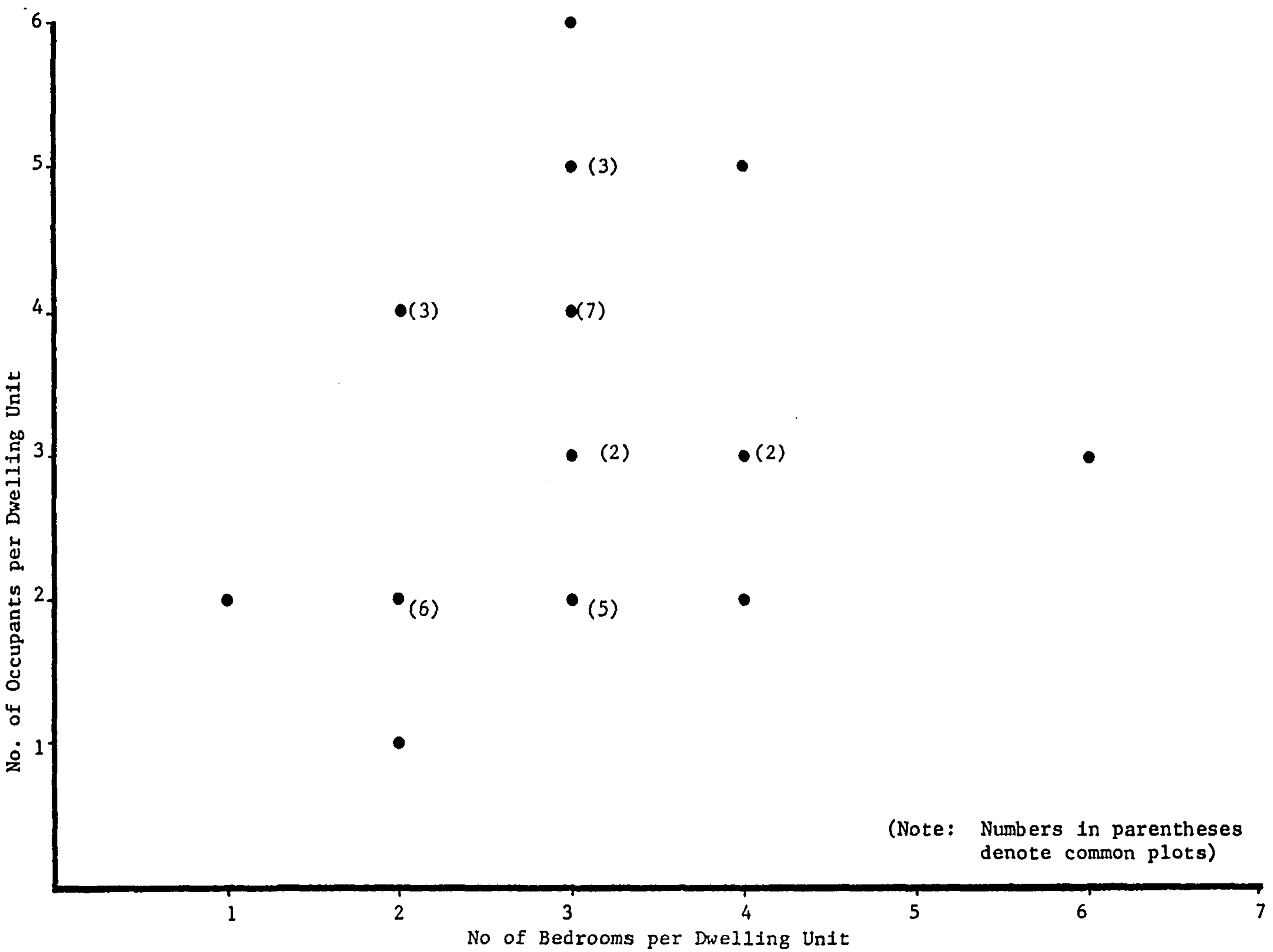


Figure 4.17 Number of Dwelling Unit Occupants Versus Reported Number of Rooms per Dwelling Unit



(Note: Numbers in parentheses denote common plots)

Figure 4.18 Number of Occupants per Dwelling Unit Versus Number of Bedrooms per Dwelling Unit and age composition and, consequently, household wastewater flow rates.

## Lagoon Seepage

Residential sewage treatment lagoons can be designed for final disposition of household wastewater by either evaporation or, where allowed, by a combination of evaporation and seepage. In Oklahoma, design standards(1) require lagoon dikes and bottoms to be constructed of impervious material which will circumvent seepage. The design, therefore, must be based upon providing sufficient surface area to evaporate of all waste flows plus incident rainfall. Although the maximum allowable seepage rate for individual residential lagoons is not specified in Rules and Regulations Governing Residential Sewage Disposal(1), Oklahoma Standards for Water Pollution Control Facilities(50) specify the seepage rate through lagoon bottoms should not exceed 500 gal/ac/day (5.4 x $10^{-7}$cm/sec) at a six foot depth.

Middlebrooks(6) has noted that wastewater seepage from lagoons has two detrimental affects: 1) seepage affects treatment capabilities by causing unacceptable fluctuations in water depth (excessive seepage can contribute to below normal operating depths and, subsequently, the establishment of nuisance rooted aquatic vegetation), and 2) seepage is a potential source of groundwater pollution. With respect to the latter consideration, the local impact of individual residential lagoons on groundwater quality would normally be minimal since these systems are usually installed in lieu of subsurface absorption field disposal systems.

## Literature Review

Mechanisms influencing the movement of water through soil such as occurs when wastewater seeps from lagoons, is discussed in the EPA design manual Onsite Wastewater Treatment and Disposal Systems(3). These are summarized below.

Since water moves through the voids or pore spaces within soil, the size, shape and continuity of those spaces are important physical properties of soil. Two of the primary characteristics are texture, i.e., the relative proportion of the various sizes of soil particles (usually classified as sand, silt and clay in various percentages), and soil structure, which is the aggregation of soil into clusters of particles, as well as the nature of the surfaces separating the particles, i.e., platy, blocky, prismatic and granular.

Fine textured or clayey soils do not transmit water rapidly or drain well because the pore sizes are very small. Well structured soils, with large voids between the particles, will transmit water more rapidly than poorly structured soils with the same soil textures. Soils in which the surfaces of weakness are platy restrict vertical percolation because the surfaces are horizontally oriented. Soil structure is easily altered or destroyed by movement of equipment, etc. and soils can be made more impervious to movement of water by compaction which changes the soil structure by compressing the soil particles into interlying voids and altering their shapes. Certain types of clay soils characteristically shrink and swell appreciably with changes in water content. This can also interrupt water movement. Clay soils are more porous than sandy soils and yet sandy soil will conduct much more water because they have larger, more continuous pores.

The primary mechanisms for movement of water through soils relate to gravitational and matric potential. Matric potential is produced by the affinity of water molecules for other water molecules and for surrounding solid surfaces. This phenomenon is well known as the capillary rise of liquid in a wick. Water rises higher and is held tighter in smaller pores. The rise of the water is halted when the weight of the water column, e.g., the gravitational pull on the water, is equal to the capillary force. The ability of soil to draw water into its pores is referred to as matric potential and increases as soil drying occurs. When soil is saturated, and all pores are filled with water, no capillary suction occurs. The influence of matric potential and capillary rise are important in affecting water loss by evaporation from soil surfaces surrounding the lagoon water surface and potentially, by water movement through the lagoon dikes with subsequent evaporation and evaporating from outside dike surfaces. Evapotransporation from vegetation on the dikes can also dissipate water which is drawn from soil in the root zones of the plants.

Gravitational potential is a more familiar concept which applies in saturated soils, i.e., in soils below the water level of the lagoon, and causes the water to move downward. In unsaturated areas, both gravity and the matric potentials determine the direction of flow which can be upward, sideward or downward, depending upon the differential affects of the two potentials. The hydraulic conductivity of soil is its ability to transmit water and is highest when soils are saturated, with all pores being water-filled. It decreases as they dry. Hydraulic conductivity is related to the number, size and configuration of pores in the soil and is lowest for clay soils which have small, discontinuous, water-filled pores which thereby offering highest resistance to flow.

Since individual residential lagoon systems are normally installed in areas which exhibit failing (greater than 60 minutes per inch of water drop) soil percolation rates, they are generally limited to areas with clay soils which exhibit low permeabilities, considerable resistance to soil water movement and, therefore, low seepage potential. Several studies (see discussions by Middlebrooks, et al.(6)) have found that natural sealing of lagoons often occurs beyond that exhibited by the soils in which the lagoons are constructed through three mechanisms: 1) physical clogging of soil pores by settled solids, 2) chemical clogging of soil pores by ion exchange, and 3) biological clogging caused by microbiological growth at the soil/water interface. The composition of the wastewater being treated has been shown to be the dominant mechanism affecting the natural sealing processes(6). At least two studies(51,52) have found that the biological clogging mechanism predominated after biological wastes were introduced into lagoons with relatively high seepage rates. In one case seepage was reduced from 48 in/day initially to .2 in/day after 4 months and, in the second, initial seepage was reduced from 4.4 in/day to .12 in/day after 6 months.

A study performed by Middlebrooks, Perman and Dunn(53) relating to wastewater stablization pond linings, indicated that removal of porous topsoil and compaction of underlying soils, in most cases, provided adequate sealing for both the bottoms and dikes of lagoons. They suggested that, when excessive percolation was still a problem, increasing the hydraulic loading and removing sand and gravel pockets could effect partial sealing. They also observed that wastewater solids eventually decreased lagoon seepage by clogging soil pores and recommended bentonite clay and asphaltic coatings as practical lagoon liners for assuring complete seals.

Middlebrooks, et al.(6), classifies three major categories of lagoon liners as including: 1) synthetic and rubber liners, 2) earth and cement liners, and 3) natural and chemical treatment sealers. One of the most extensive studies of various infiltration characteristics and chemical and physical additives for pond sealing was conducted in 1976 in New Zealand on anaerobic lagoons by David J. Hills as reported by Middlebrooks, etal.(53). The Hills studies evaluated the effectiveness of chemical and mineral additives in reducing infiltration rates of lagoons constructed in different types of soil and, more important, the infiltration rates in untreated soils of different types and at different lagoon depths. While little change was observed in initial infiltration rates as compared with the eventual infiltration rates of lagoons constructed in clay loam soils, the infiltration rates of lagoons constructed in loam, silt loam and sandy loam soils dropped from initial values ranging from approximately 2.5 to 7 $l/m^2$/day (.061 to .172 gal/$ft^2$/day) to approximately 1 $l/m^2$/day (.024 gal/$ft^2$/day) within 12 to 16 weeks, after which the infiltration rates remained stable. Lagoon depths were approximately 3 meters and soil thicknesses ranged from 15-35 cm. Middlebrooks, etal.(53), notes that natural clays are frequently more impermeable than remolded clays and consequently recommends that they not be disturbed except in areas where cracks or other leakage passways make it necessary to circumvent seepage.

Studies by the Minnesota Pollution Control Agency(54), reported by Middlebrooks, et al.(6), determined, in evaluating groundwater samples from monitoring wells near 5 municipal lagoon systems ranging in age from three to seventeen years, that sludge accumulations reduced permeability of bottom soils in permeable soils but were insignificant in effecting this reduction in relatively impermeable soils. Groundwater samples from monitoring wells did not show significant increases in nitrogen, phosphorus or fecal coliforms above background levels but did indicate increases in soluble salts as much as twenty times above background levels downgradient from the ponds.

The puacity of reported seepage rate data from operating lagoon systems in the literature is apparent in a recent summary of these data by Middlebrooks, et al.(6). Reported seepage rates of systems which had been installed long enough to have reached stable seepage levels located in California, Nebraska, Michigan and Illinois ranged from .30-.61 in/day corresponding to 6,800-13,810 gal/ac./day (.156-.317 gal/ft$^2$/day). Three of the rates were for systems in clay loam to sandy soils and were between .3 and .35 in/day (6,800-7,940 gal/ac./day with the remaining higher seepage rate figure pertaining to a lagoon constructed in sand and gravel.

Middlebrooks, et al.(53), in a seperate publication also summarize state design standards for wastewater stabilization lagoons, including allowable seepage rates. At the time the data were compiled(1978), thirty-three states did not specify a specific allowable seepage rate from these facilities. Some of the states required impervious liners, however. The most common reported maximum allowable seepage rate(eight states) was 1/4 in/day. Three states allowed a maximum seepage of 1/8 in/day, one state allowed seepage of 1/16-1/8 in/day, and one state specified a maximum rate of 1/16 in/day. A lagoon bottom coefficient of permeability not to exceed 1 x $10^{-7}$cm/sec was specified by three states while one state indicated no seepage was allowable.

## Lagoon Seepage Rate Analysis

Seepage rates for each of the onsite residential lagoon systems surveyed in this study were determined as residuals using water balance (water budget) techniques in which seepage was assumed to represent the difference between water inputs (wastewater influent and precipitation) and water losses (evaporation). Specifics of the techniques involved have been previously discussed in Chapter III. The intensive stabilization pond seepage study conducted by the Minnesota Pollution Control Agency(54) calculated seepage estimates by utilizing both water balance methods and by conducting in-place field permeability tests on the bottom soils of the lagoons. Good correlations were obtained using both techniques.

In the water balance equation, the relative impacts of precipitation gains and evaporative water losses on seepage are proportional to their respective areas of impact. For example, the total quantity of precipitation entering a lagoon is proportional to 1) the water surface area which receives incident precipitation plus 2) the vertical projection of the surrounding catchment area (the dike surface that will contribute precipitation runoff into the facility.) Evaporation is proportional to the water surface area, while seepage is generally considered to be proportional to the bottom area, although the wetted dike area (the area of dike below the water surface) represents additional potential area for seepage. Some amount of evaporative loss from the lagoon dike area and evapotranspiration from vegetation above the water surface, wetted as a result of capillary rise, also occurs. The relative proportions of surface and catchment areas for the systems studied varied widely and often not in direct relation to bottom design area. The average bottom design area of the studied lagoons was 1,013 $ft^2$ ranging from 400-1,800 $ft^2$. Mean surface area during the study averaged 2,884 $ft^2$ with a range of 1,472-4,692 $ft^2$. Net precipitation catchment area (vertical projection of inside dike surface area about water level) averaged 2,249 $ft^2$ during the study and ranged from 1,161-4,193 $ft^2$.

Water balance computations to determine seepage rates were completed for 30 of the 33 systems studied. Three systems were excluded from these calculations; two due to evidence of having overflowed during the course of the studied (one system had obviously reduced volume as a result of dike erosion and siltation). The facilities exhibited a wide range of seepage during the course of the study varying from 21 gal/day to 556 gal/day. The mean seepage rate for all facilities was 317 gal/day with a median of 320 gal/day. In terms of inches, the mean seepage rate was .202 in/day ranging from .012-.481 in/day. The median rate of seepage for all systems was .18 in/day with a calculated standard deviation of .119 in/day. Probability distributions of average daily seepage from all of the facilities are presented in Figure 4.19 and 4.20 in gal/day and in/day, respectively.

The 500 gal/ac./day maximum seepage rate allowed by Oklahoma Standards for Water Pollution Control Facilities(50) is equivalent to .0184 in/day. By reference to Figure 4.20 it is apparent that more than ninety-six percent of the facilities studied exhibited seepage rates in excess of that figure, which, according to Middlebrooks, etal.(50), represents the current recommended design seepage rate and is felt to be a good guide for designing primary oxidation ponds.

The impact of the seepage component on the water balance equation is surprisingly large, relative to evaporation and precipitation, as is obvious in Figure 4.21 which presents the component gains and losses in gal/day for each of the systems studied. In that figure the systems are arranged in order of increasing bottom design area. An important observation which can be made from that figure is that influent flows do not obviously increase with increasing design as would be anticipated. Evaporation losses and precipitation inputs to the systems do exhibit very general, but highly variable, direct increases as design area increases due to the increasing size of the catchment areas and the relatively even distributions of rainfall for all of these facilities. Most important, it is also obvious in Figure 4.21 that the losses due to seepage from many of the facilities are greater than influent flows, on an average daily basis, and, in nearly all cases, exceed losses due to evaporation.

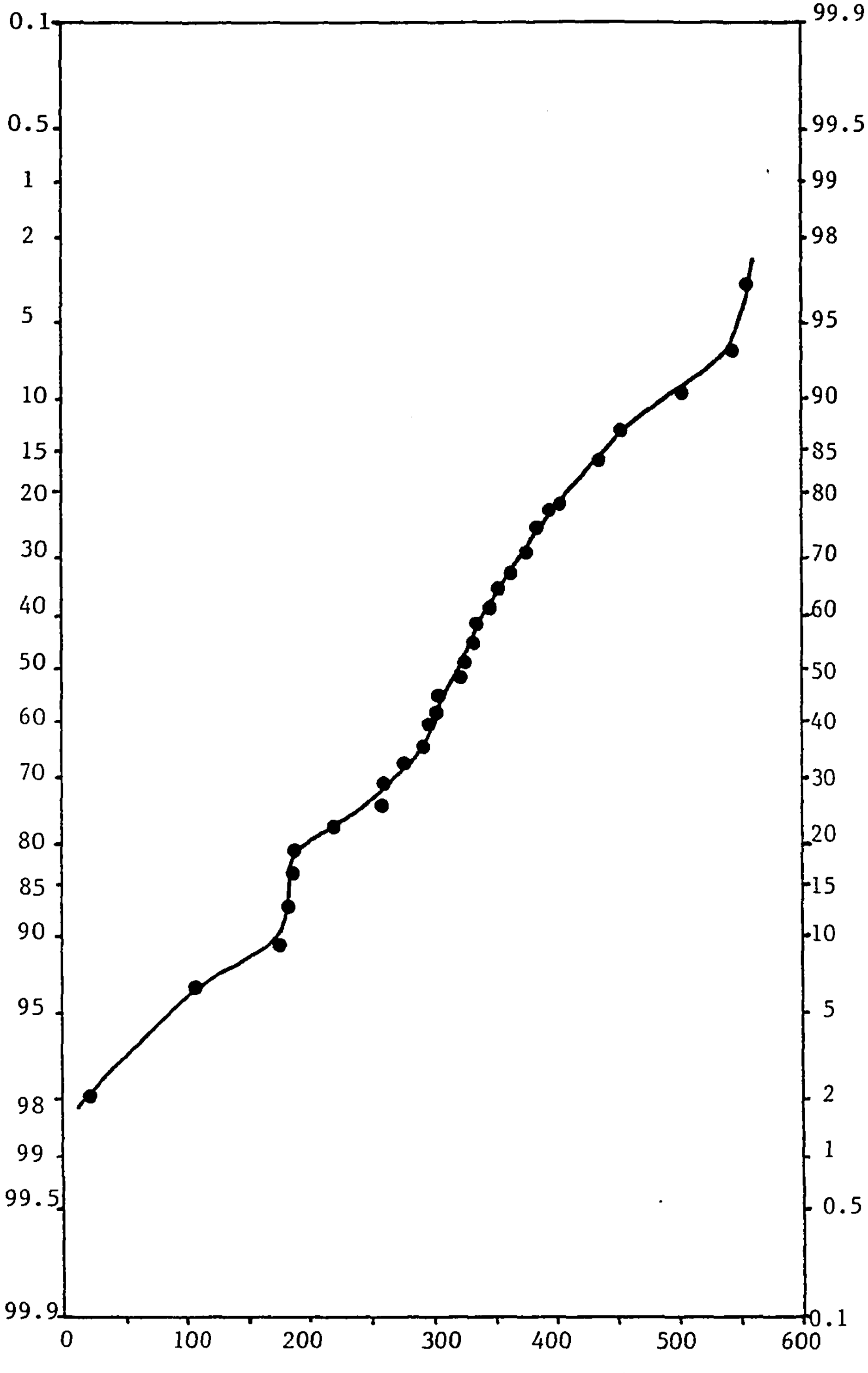


Figure 4.19 Probability Distribution of Surveyed Tulsa Area Lagoons by Average Daily Seepage Rate in Gallons

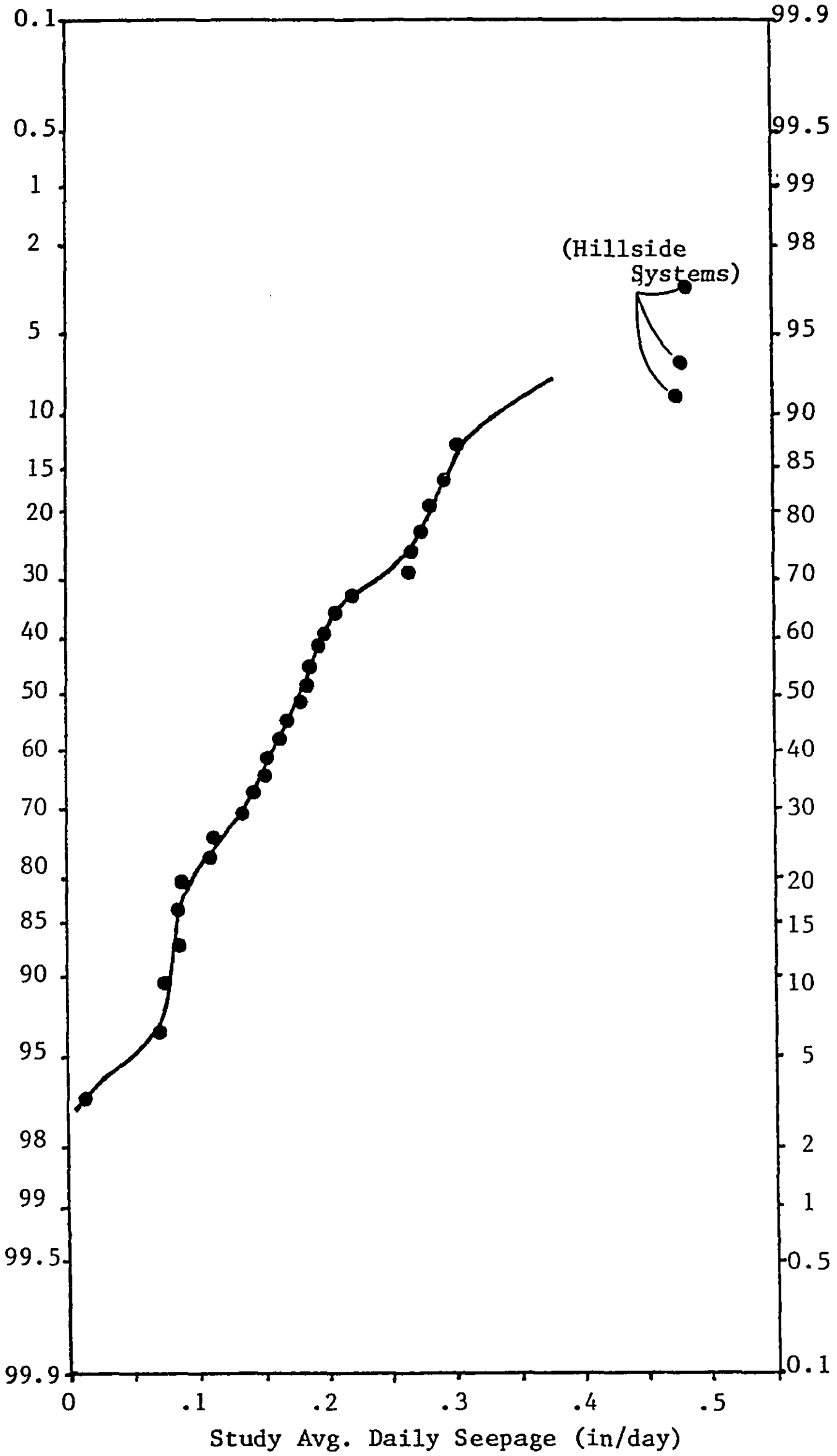


Figure 4.20 Probability Distribution of Surveyed Tulsa Area Lagoons by Average Daily Seepage Rate in Inches

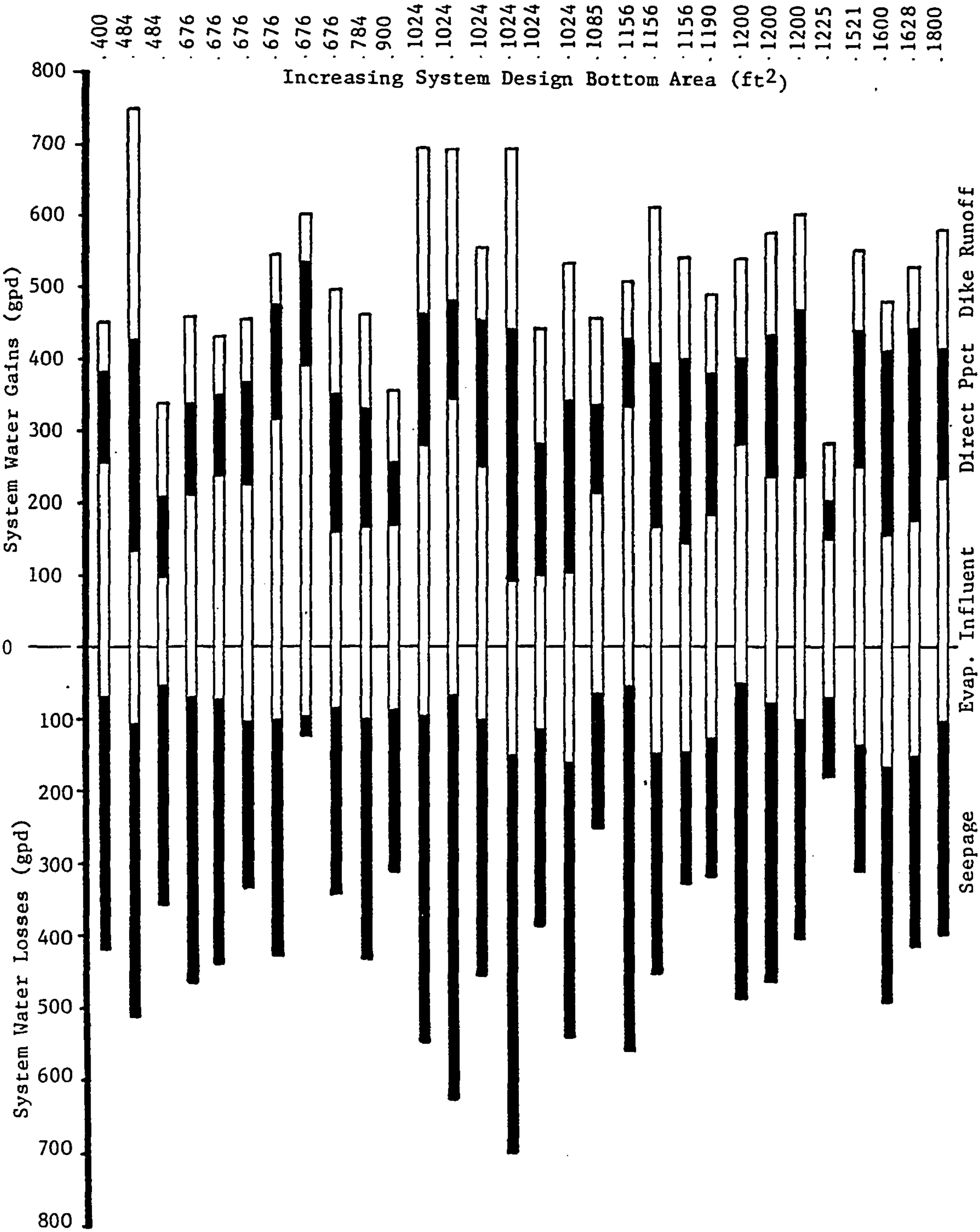


Figure 4.21 Surveyed Tulsa Area Lagoon System Average Daily Study Period Water Balances in Gallons

The contribution of precipitation to the water balance equation, as previously mentioned includes two components: 1) incident precipitation entering the lagoon pool by falling directly upon the water surface, and 2) the runoff of precipitation excess from the lagoon dikes (i.e., the runoff of that rainfall which exceeds the infiltration capacity of the dike soils). The first component was calculated by simply multiplying cumulative rainfall for the study period (derived from isohyetal distribution maps) by the study average water surface area. Estimation of the precipitation runoff component from the surrounding dikes required the detailed study of two additional lagoon systems in the Tulsa area (see Chapter III) in order to establish reliable relationships between precipitation, infiltration and runoff.

As discussed in Chapter III, the two systems selected for additional study to evaluate lagoon dike precipitation-runoff relationships, included a facility serving a church and parsonage and one serving a truck sales and service firm. Both of the lagoons were located in east Tulsa and, for convenience of field observation, were approximately one mile apart. Techniques for water balance component and physical measurements made at the facilities were identical to those of the other thirty-three surveyed residential facilities. Construction of the lagoons was identical to residential facilities although both systems were larger than normal residential lagoons. The facility serving the church had a design bottom area of 4,224 square feet (66' x 64') with an eight-foot dike top width and a six-foot depth. In actuality, field measurements showed the lagoon to be only four feet deep. This lagoon was constructed on a level site with the dikes configured such that approximately half of the lagoon depth was below the natural grade and half above grade.

The facility serving the truck sales and service firm was somewhat larger than the church facility having a design bottom area of 4,312 $ft^2$ (56' x 77'). However, this lagoon was constructed on a lot with an east to west slope resulting in a much deeper elevation on the east side (the top of the east dike was approximately six feet above the top of the west dike) which subsequently resulted in a larger precipitation catchment area due to the long east dike slope. More important, this facility was designed such that essentially all of the seven-foot design depth was below the surrounding grade since the excavated soils were spread over the lot surrounding the facility and distinct dikes, as such, were not constructed.

The precipitation runoff study of these facilities was commenced on September 18 and continued through the end of December, 1984. During that time eighteen precipitation events occurred and were evaluated with regard to their runoff impact on the operation of the facilities. After the data were evaluated, it was determined that, with respect to evaluating precipitation-runoff relationships, a longer term of study, during all seasons of the year and including varying evaporation and rainfall conditions would have been desirable since many of the rainfall events evaluated occurred when evaporation rates were low, soil moisture levels high, and high percentages of precipitation excess runoff occurred from the lagoon dikes.

The percentages of precipation runoff were much more varied at the facility serving the church than that serving the truck sales firm. The reason for this greater variability was not entirely apparent, but was evidently related, in part, to the higher seepage rates associated with the former facility. Only those measurements which could be obtained within 24 hours of a precipitation event were retained for use in the computation of runoff relationships. Because of the variable nature of lagoon water level fluctuations, increases in lagoon operating level following precipitation events was based upon the rise above the projected lagoon level indicated by a rising or falling trend immediately preceeding the precipitation event. Precipitation runoff was determined as the excess rise beyond that which would have resulted from rainfall incident to the water surface.

A variety of statistical analyses were conducted on the dike precipitation runoff data collected from these facilities. Multiple regression analyses of the data utilizing daily evaporation rates and current event precipitation levels, plus antecedent precipitation amounts during the immediately previous ten-day period at two-day intervals, were highly significant and produced multiple correlation coefficients exceeding .95 for both facilities. However, the regressions could not be used since they tended to predict negative runoff percentages at low rainfall levels and required event oriented input variables which could not be employed in general design model equations based upon monthly and/or annual time periods.

The relationships observed between precipitation and precipitation runoff from lagoon dikes obtained during the study were characterized by considerable variance. This is evident in Figure 4.22 which is a plot of the data collected during the study. This is not unexpected since runoff occurs when the rate of rainfall exceeds the soil infiltration rate, either because soil moisture levels are nearing saturation or the rate of rainfall is greater than the rate of infiltration, regardless of soil moisture levels. As a general rule, when soil moisture contents are high, more runoff can be expected to occur since soil moisture will reach saturation quickly, whereas when soil moisture levels are low, less runoff will occur because infiltration rates are high. On the other hand, intensity of rainfall can greatly affect precipitation runoff rates since intense rainfalls can greatly exceed infiltration rates producing higher percentages of runoff. Rainfall infiltration is often estimated from typical infiltration curves such as that reported by Viessman, et al.(11), which generally depict rapidly decreasing soil infiltration rates during the initial hour of rainfall after which the rate of decrease quickly levels off. Initial infiltration may be five times greater than those occurring after one hour.

For purposes of evaluating and modeling rates of runoff within monthly or annual time frames, longer termed, general precipitation-runoff relationships were desired rather than event oriented relationships. It became apparent during the analysis of the data from the runoff study sites that such general relationships between runoff and precipitation could be based upon average daily evaporation as a surrogate measure of soil moisture conditions. The precipitation runoff plots shown in Figure 4.22 have been aggragated into three groups corresponding to the following specific ranges of average daily evaporation existing during the study: 1).05-.09 inches, 2).10-.14 inches and 3).15-.19 inches. The average percent runoff occurring from

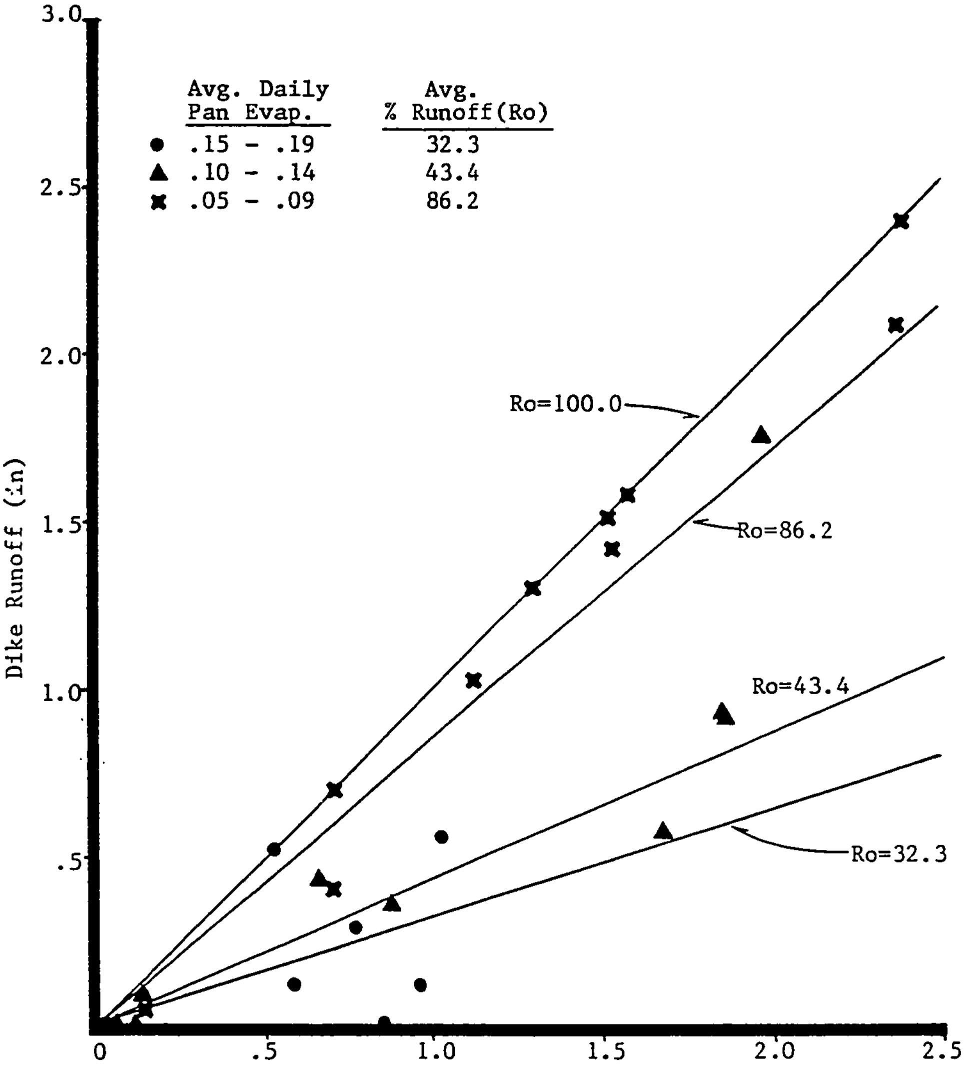


Figure 4.22 Precipitation Versus Dike Runoff in Inches, Classified by Average Daily Pan Evaporation Rate for Tulsa County Runoff Study Sites.

events within each of these ranges were 86.2%, 43.4% and 32.3%, respectively.

The percentages of runoff versus average daily evaporation rates have been plotted in figure 4.23 for each of the study events. It is obvious in that figure that runoff nears 100% when evaporation rates approach those prevailing during the winter months, generally less than .08 inches per day. The percentage of precipitation runoff decreases rapidly as evaporation rates rise and, although considerable variance exists in the event data, it is obvious that percent runoff for precipitation events occurring during the higher evaporation months tend to be very low. Unfortunately, the study period did not include months of average daily evaporation greater than .19 inches. The warm weather months of May through September experience average daily evaporation rates greater than those occurring during the study, with July being the highest at approximatley .32 inches per day.

The curve dipicted in Figure 4.23 is a "free hand" best fit of the available data and has been projected at the lower end (dashed portion of curve) to approximate possible runoff percentages during the warm weather months. Although the projected portion of this curve is speculative, it is evident from the data presented in that figure that the error there cannot likely exceed ten percent since runoff percentages are less than twenty percent entering the warm weather months and cannot fall below zero. Additional data collection to establish the precise percentages of runoff from rainfall events occurring during warm weather months would aid in improving the accuracy of this procedure which provides the basis for dike runoff inputs into

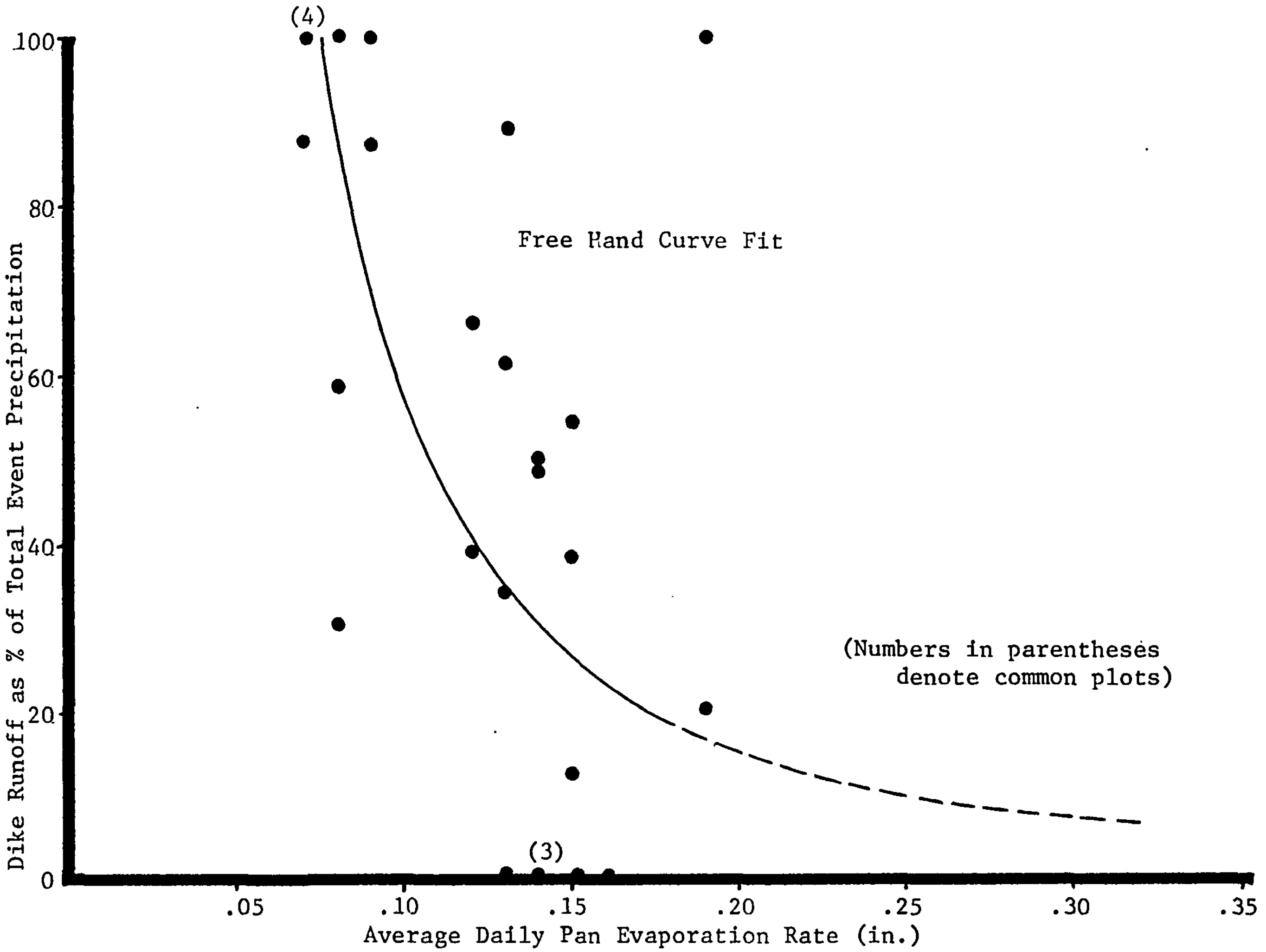


Figure 4.23 Average Daily Pan Evaporation Rate Versus Dike Runoff as a Percentage of Total Event Precipitation for Tulsa County Runoff Study Sites

the design model. Seepage rate determinations for the thirty-three surveyed lagoon systems were not affected by the percent runoff curve projection since the study period was confined almost entirely to months during which runoff rates were near 100%. Only two rainfall events occurred during March in which runoff rates were less than 100%, all the other events (eight) occurred at times when average daily evaporation available for the study indicated 100% runoff conditions prevailed.

Measurements were made at the dike runoff study sites two to three times per week during the approximately three and a half month study period. From these data, nearly continuous water balances could be developed for both of the studied systems depicting the influences of all major water balance components including influence, evaporation, rainfall and dike runoff and the results compared with actual lagoon operating level data. These data are graphically presented as Figures 4.24 and 4.25 for the church and trucking firm systems, respectively. An unexpected benefit of completing the more detailed studies on these two systems was the much improved understanding and predictability of lagoon seepage which resulted from the different construction configurations of the two systems, i.e., one being conventional with approximately half of the lagoon volume below original grade and the other being essentially 100% below grade.

It is obvious in Figures 4.24 and 4.25, in which cumulative seepage is indicated by shading, that the facility serving the church exhibited considerable seepage during the study totaling well over fifty percent of the total liquid gain to the facility. On the other hand, the lagoon serving the truck sales and service firm exhibited virtually no seepage

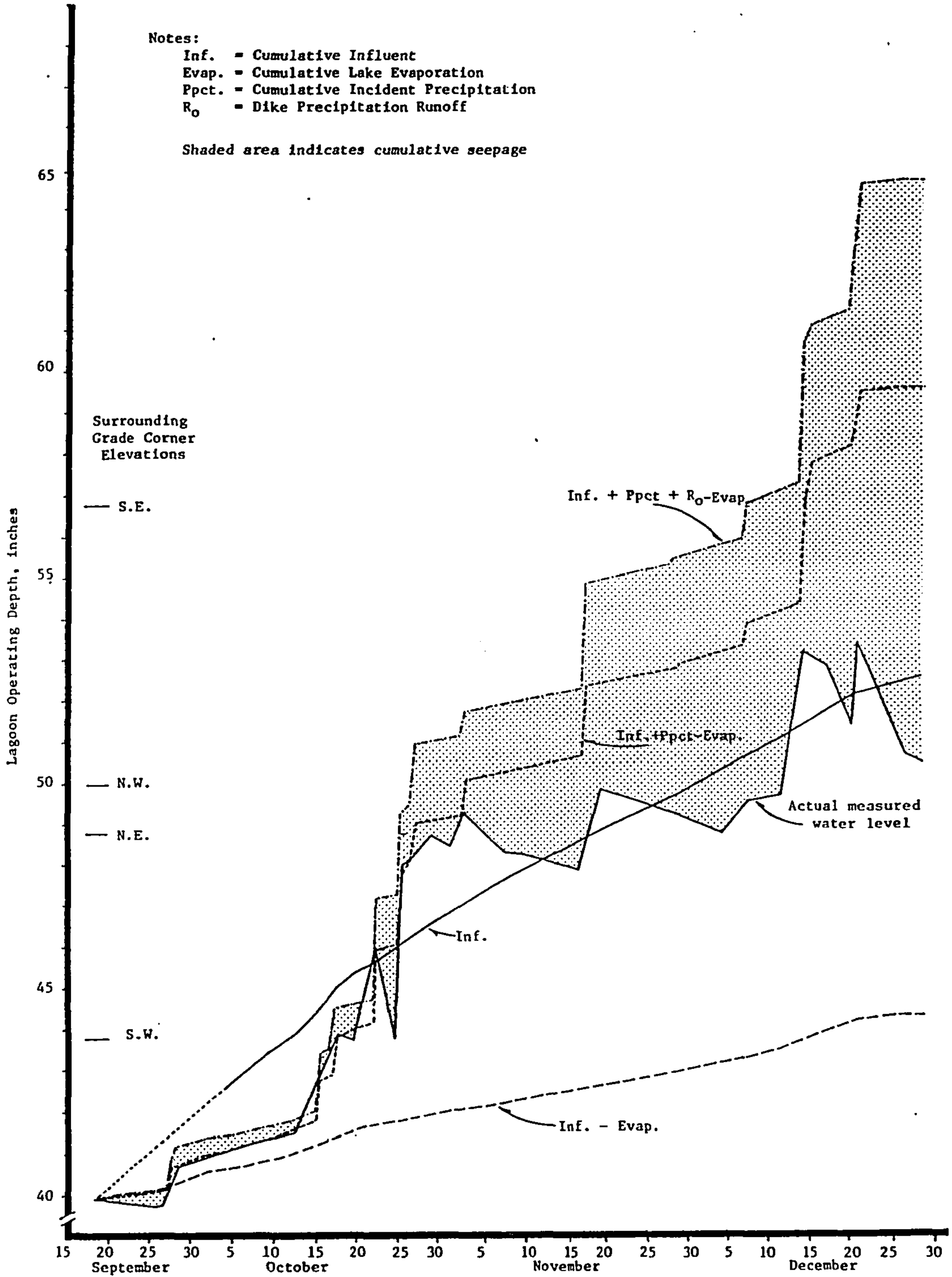


Figure 4.24 Cumulative Component Water Level Balance of Church of God Lagoon System for Study Period, September 15-December 28, 1984

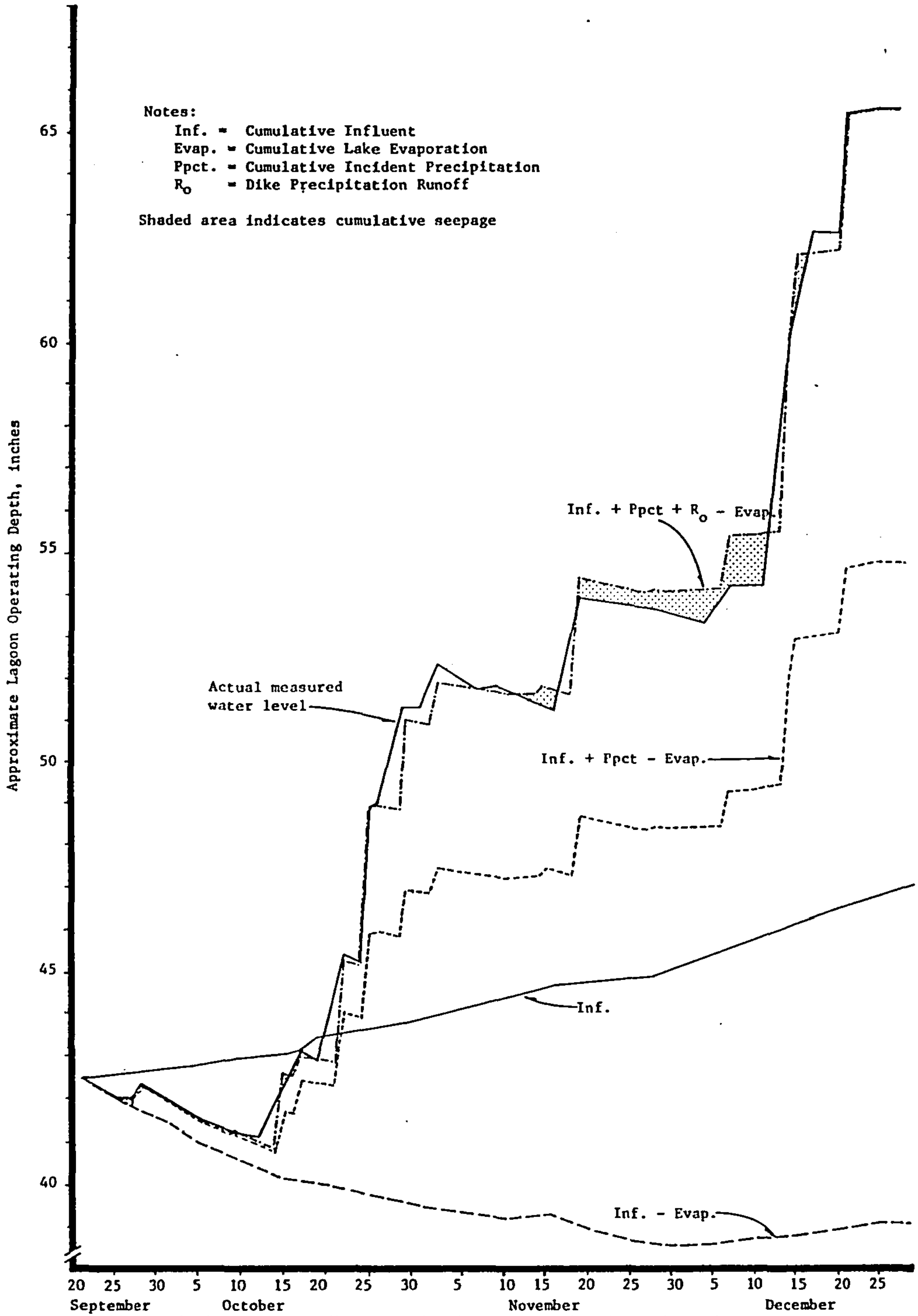


Figure 4.25 Cumulative Component Water Level Balance of Truck Sales and Service Firm Lagoon System for Study Period, September 20-December 28, 1984

with the calculated cumulative potential water level matching the actual onsite measured water level almost exactly throughout the study.

By reference to Figure 4.24, it is apparent that little seepage from the church facility occurred until the operating water level rose above the lowest level of the surrounding grade (southwest corner). This occurred around October 21, 1984. After that time, considerable seepage occurred following each precipitation event as the water level rose progressively above the surrounding grade. It is also apparent in Figure 4.25, that, as previously mentioned, no seepage occurred from the truck sales firm lagoon which is effectively all below the surrounding grade. These data strongly support the supposition that seepage through lagoon bottoms and dike areas below grade is insignificant, at least during the winter months and, conversely, that virtually all lagoon seepage which occurs, does so through the dikes in the area above the level of the surrounding grade. General observations following precipitation events indicate that such seepage occurred rapidly (most of the water was lost within hours) as soils in the surrounding dikes were recharged with water from the lagoon. The rate of seepage dropped to a low level soon thereafter, however, leaving a slight rise in lagoon level following most precipitation events as some rainwater was retained. This may be a result of the activation of the biological clogging mechanism previously discussed (51, 52) due to the presence of sufficient moisture to allow such biological growth to occur or, perhaps, a result of the swelling of wetted natural clays in the surrounding dikes.

Prior to the collection of the seepage data from the dike runoff study sites, correlation and regression analyses involving a number of physical parameters for each of the thirty-three surveyed lagoons was carried out in an attempt to explain a portion of the substantial variance in seepage rates observed at these facilities. Results were generally not good although some statistically significant relationships were confirmed which reduced a small percentage of that variance. The seepage data for each facility were transformed into several different equivalent forms for regression and correlation analyses. These included total average daily seepage in gallons per day, average daily seepage in inches per day per square foot of lagoon bottom area, inches per day per square foot of average water surface, and others. Although seepage rates are conventionally determined in terms of quantity loss per square foot of lagoon bottom, other lagoon surface areas which theoretically provide additional opportunities for seepage either through gravitational or matric potential forces were examined for their relationships with seepage data. These included average water surface area, the total wetted area of the lagoon bottom and dikes, the wetted dike area, and the estimated wetted dike area above the surrounding grade.

Regression analyses based upon these transformations generally failed to substantiate statistically significant relationships among most of these variables. However, a trend toward generally consistent inverse relationships between the surface area variables and lagoon seepage rates was often noted. An example of one of the stronger of these relationships relating lagoon design bottom area to average daily study seepage in inches per day is presented as Figure 4.26. The

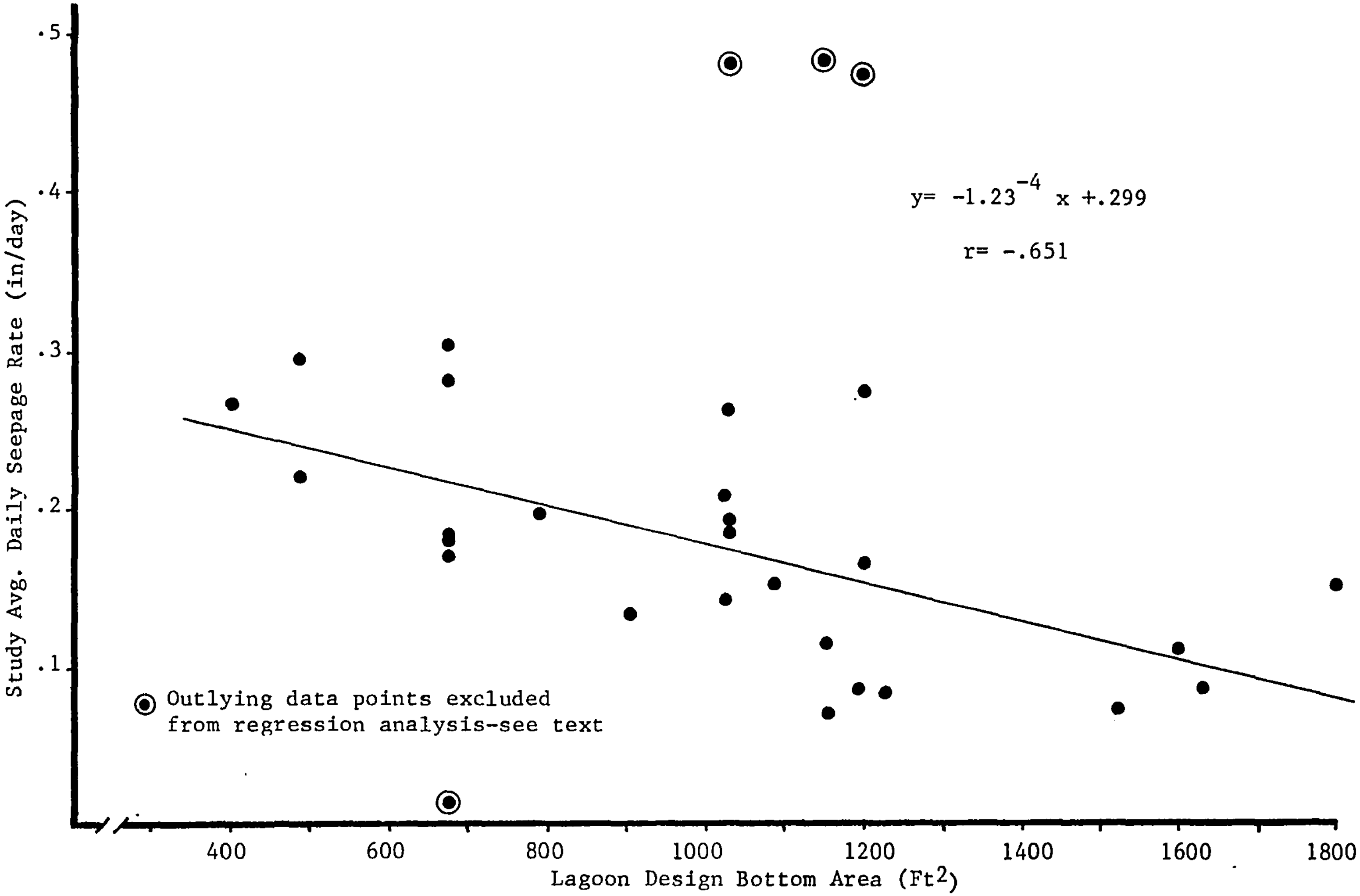
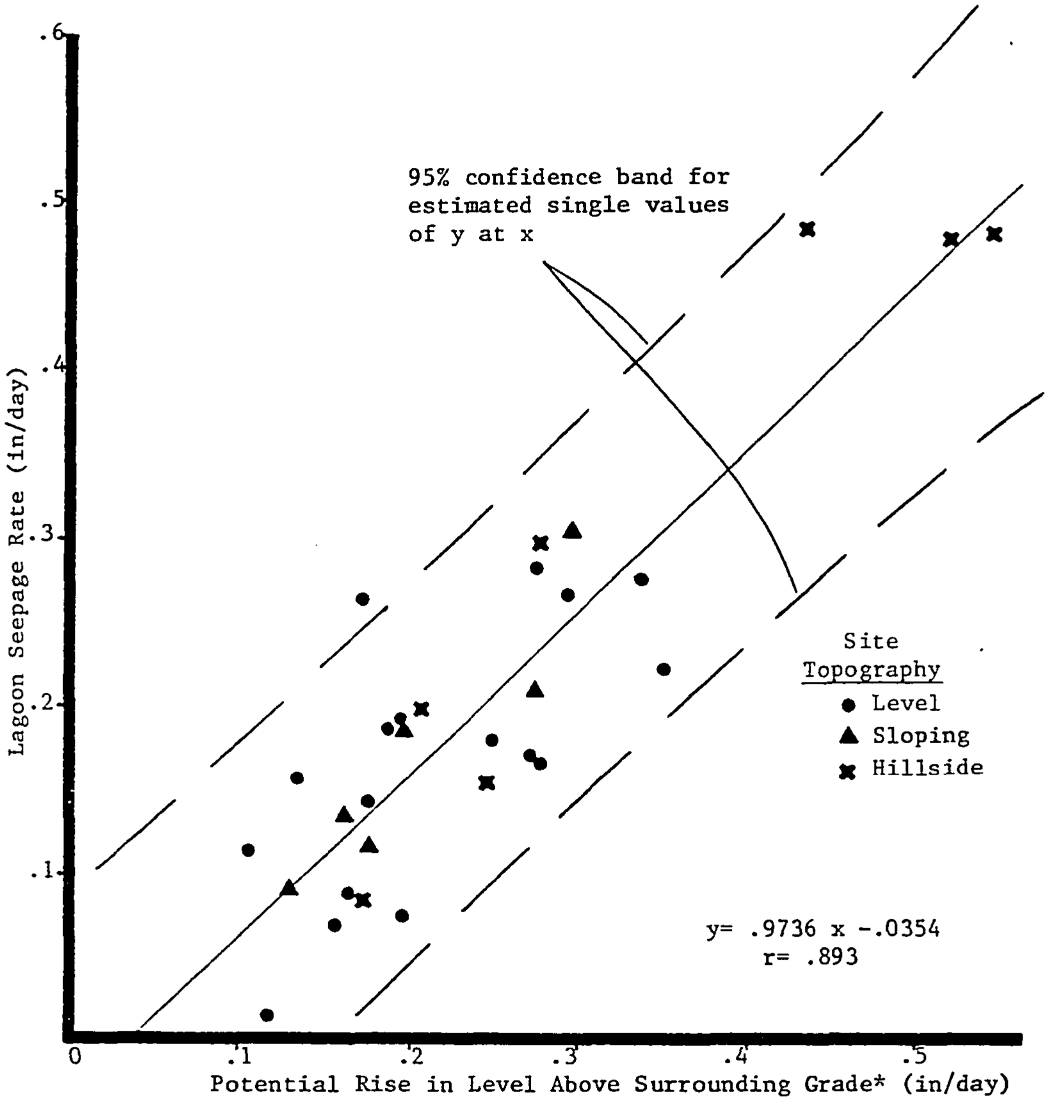


Figure 4.26 Surveyed Tulsa Area Lagoon Design Bottom Areas Versus Average Daily Seepage Rates in Inches

explanation for the generally poor but inverse relationship between lagoon area parameters and seepage rates lies in the fact that seepage is related simply to water depth above grade and is completely independent of lagoon area parameters, e.g. larger system water levels rise less (due to relatively smaller volumetric gains from dike runoff and wastewater influents) and, therefore, exhibit less seepage.

For mathematical modeling purposes, it was necessary to relate lagoon seepage to potential rise resulting from influents and precipitation determined on monthly or annual bases rather than at the event level. Analyses of seepage and water level data collected for the thirty-three participating lagoon systems (only thirty were actually included in the analysis) were evaluated to develop such a relationship. Unfortunately, the need for exact onsite measurements relating dike elevations and lagoon bottom elevations to surrounding grade levels were not anticipated and, therefore, not obtained. It was consequently necessary to assume all systems but those constructed on hillsides were built half above and half below the surrounding grade, which is commonly the case. For most systems this distinction was not important, it was apparent during site visits that, since nearly all systems were operating above the assumed natural grade during the period of study. The potential rise in level above the surrounding grade was defined for the study period as the rise that would result from the contributions of both influents and precipitation (incident as well as runoff), less evaporation. The potential rise in inches per day was related, by regression analysis, to lagoon seepage in equivalent units. Results of this relationship are shown as Figure 4.27, along with



(*Potential rise is rise which would result from influent,precipitation, and dike precipitation runoff inputs, less evaporation assuming no seepage occurs).

Figure 4.27 Potential Rise in Lagoon Level Above Surrounding Grade Versus Seepage Rates of Surveyed Tulsa Area Systems confidence bands for estimating individual values of seepage from potential rise. In that figure, the data points are depicted separately for systems constructed on level, sloping, and hillside sites. While little distinction is apparent for most of the systems based upon site topography, three of the hillside sites are obvious outliers with respect to exhibiting unusually large seepage rates. This is more evident in Figure 4.26 in which the three hillside systems lie in a group well removed toward the top of that figure. The large seepage rates from the hillside systems are consistent with the suggested lagoon dike seepage hypothesis which presumes virtually all seepage is through the lagoon dikes above the surrounding grade. On hillside systems, the surrounding grade would lie nearly at the bottom of the facility, depending upon the specific site topography.

Middlebrooks, et al.(50) has reported that seepage is a function of so many variables that only extensive soil tests make it possible to anticipate or predict seepage rates. The EPA design manual for municipal wastewater stabilization ponds(7) states that, even with extensive soils tests, the prediction of such rates is impossible. The possible relationship between seepage rates among Tulsa County systems and soil type was examined in the hope of further explaining seepage rate variances. The residential lagoon systems surveyed in Tulsa County were distributed among thirteen different soil types as classified by the US Department of Agriculture, Soil Conservation Service(55). Because of the large number of separate classifications involved, the number of systems installed in any one soil type was too limited to evaluate differences in seepage rates which might be associated with certain soil classes. The distribution of the Tulsa area systems by average daily seepage rate in inches and USDA Soil Classification are shown in Figure 4.28. Only soil classes numbers 12, 43, and 44, corresponding to Dennis Silt Loam, Okemah Silt Loam and Okemah-Parsons-Carrytown Complex, contain more than two lagoon facilities. The ranges of seepage rates of facilities in those classes is considerable and, therefore, little useful additional information pertaining to seepage variance reduction could be derived from this examination.

## Residential Demographic Change Analysis

A major emphasis of this research on residential lagoons was to identify significant predictive relationships between household social and physical variables and wastewater flows. The results of the study consistently indicated the best predictors of household wastewater flows are demographic and social characteristics, i.e., number and age of dwelling unit occupants, rather than physical dwelling unit characteristics such as numbers of bedrooms, floor area, etc. Although social characteristics are usually identifiable at the time the dwelling is constructed, they are subject to significant change when the housing unit is sold or rented, and subsequently occupied by a different family. For this reason, it is preferrable for residential lagoons to be designed on the basis of relatively unchanging physical dwelling unit characteristics which bear some relationship to the volume of waste flow from the household throughout the design life of the facility. Unfortunately, as has been demonstrated in this research, and repeatedly

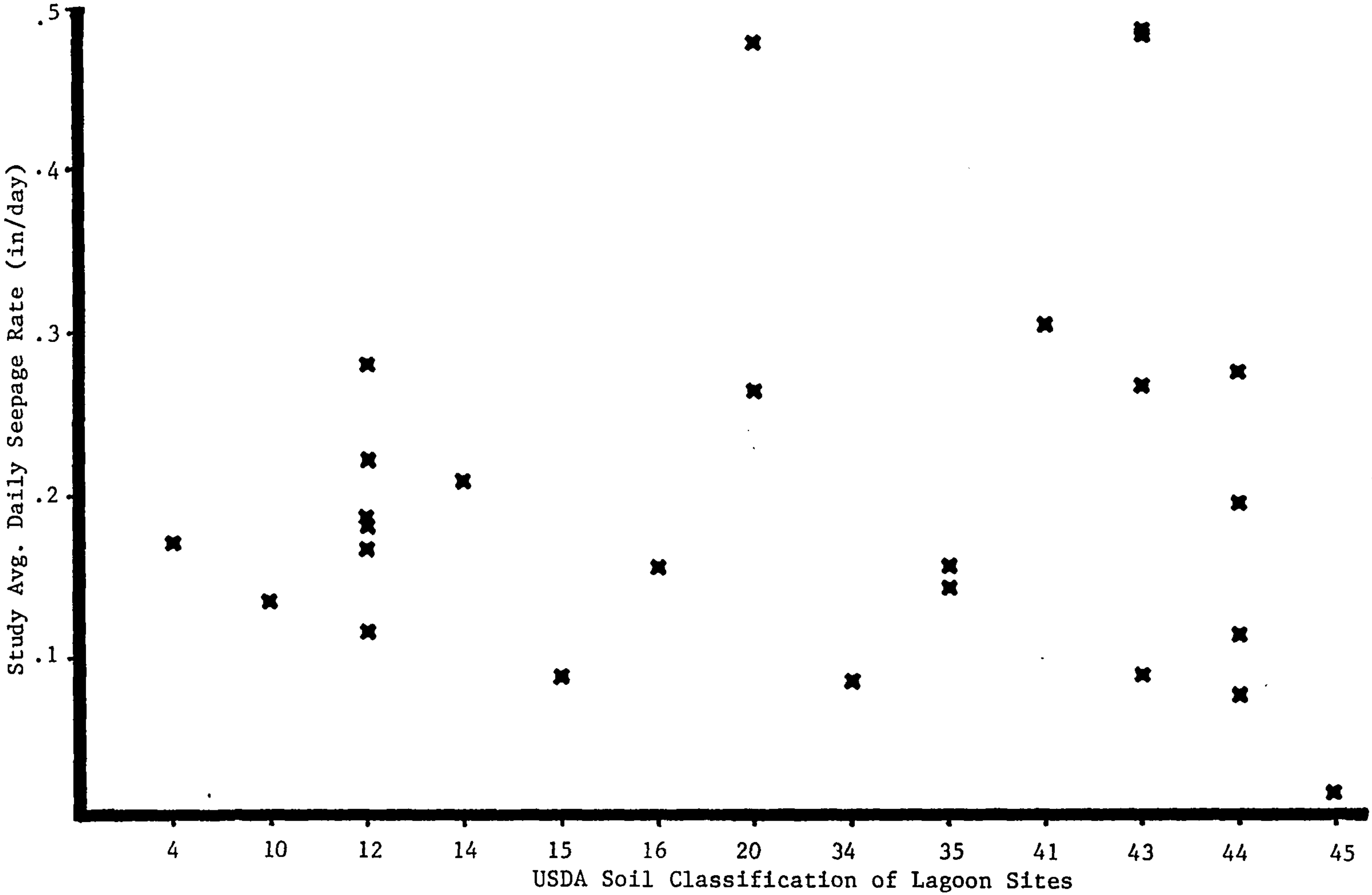


Figure 4.28 Classification of Surveyed Tulsa Area Lagoon Systems by Average Daily Seepage Rate and U.S. Department of Agriculture Soil Classification of Site

in other studies, little correlation can be demonstrated between the physical characteristics of the average dwelling and the wastewater flow exhibited by its occupying family.

In order to avoid reliance solely upon mean values which reflect the average waste flows for typical families (the basis for most state design criteria), demographic data for the Tulsa area were examined in the hope of identifying predictable trends in household demographic and social variables as they change over time. As is the case with many demographic studies, the most accessible and accurate demographic data source available, and the one used for this analysis, was decennial census data. A detailed discussion of the use of census data in these analyses is contained in Chapter III.

Although average physical characteristics of the census tract dwelling units included in the analysis remained relatively constant between censuses, some changes did occur. Since the dwelling units included in the analysis were built prior to 1960, the percentages of units containing more than one bathroom were relatively low compared with tracts including large numbers of newer single family dwelling because the popularity of more than one bathroom per dwelling unit has increased significantly in recent years. The percentages of the dwelling units with more than one bathroom increased overall for the fifteen census tracts included in the study from 1960 through 1980, averaging 12.1%, 18.2% and 20.5% during 1960, 1970 and 1980 respectively (see Figure 4.29). A significant portion of this increase can be attributed to the construction of new dwelling units in some tracts, although a portion also probably resulted from the addition of bathrooms

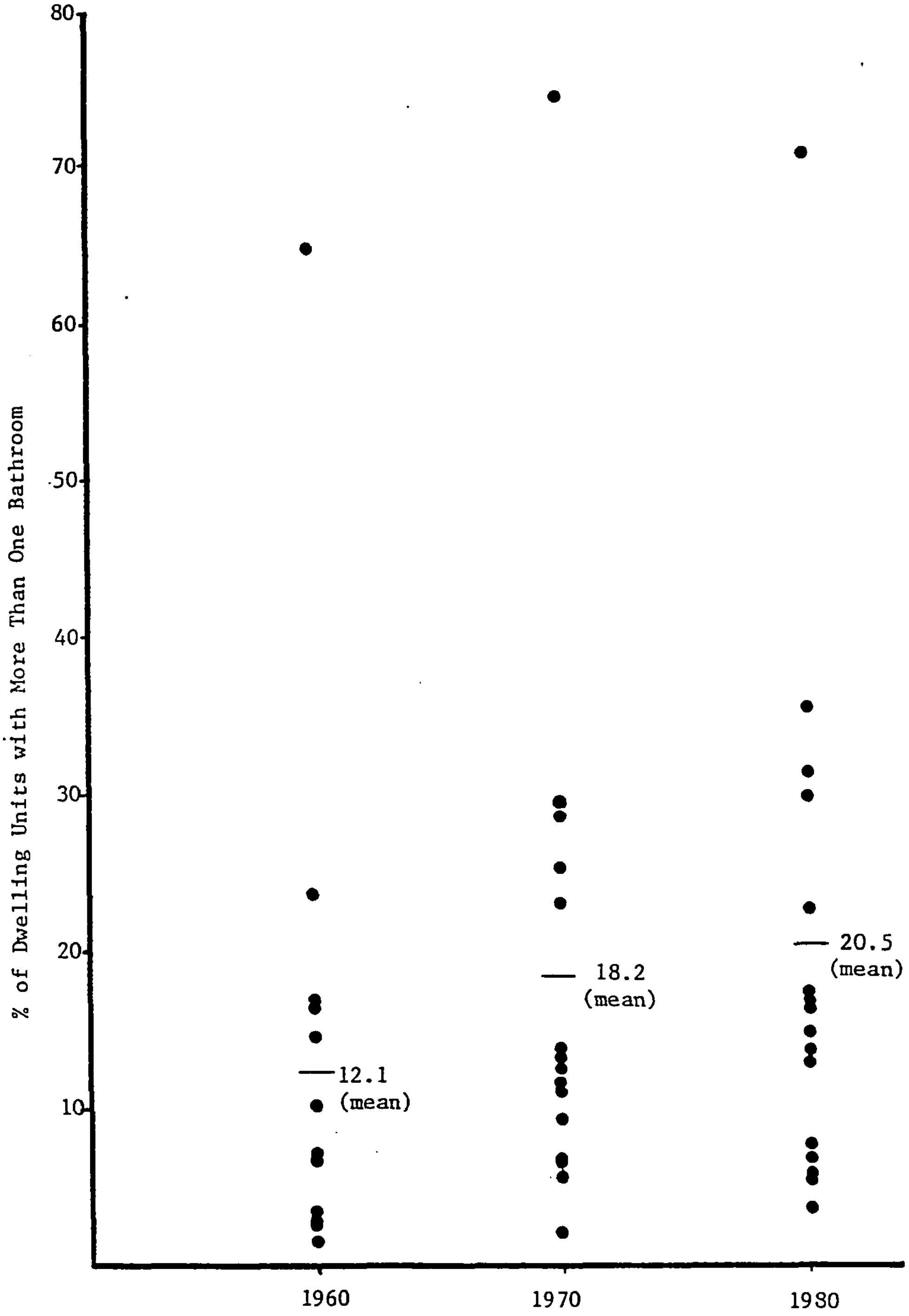


Figure 4.29 Percentages of Owner-Occupied Dwelling Units Reporting More Than One Bathroom in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

during remodeling of older homes.

The largest percentage of dwelling units in the tracts studied (approximately 35%) contained five rooms. About nineteen percent contained four rooms and approximately twenty-six percent contained six rooms. The distribution of all dwelling units, by numbers of rooms per unit as reported in the 1960, 1970 and 1980 census, are shown in Figure 4.30. This compares with a median number of rooms per dwelling unit participating in the residential lagoon survey of 6.1 rooms per unit. The distribution of rooms shown in Figure 4.30 is relatively constant between the three censuses, implying general consistency of responses to the census question concerning housing unit rooms. The slight increases between censuses in the percentages of the dwelling units exhibiting seven and eight or more rooms which can be observed in that figure may reflect the tendency toward construction of larger dwelling units in some tracts. It is important to note that the census definition of rooms may differ from common interpretation in so far as the census counts of rooms does not include bathrooms, porches, balconies, foyers, halls, or half rooms(18).

One of the more important purposes of the demographic change analysis was to examine trends in length of occupancy of dwelling units. If a residential lagoon system is designed to accomodate wastewater flows from a household exhibiting certain waste flow characteristics, an important concern is the length of time the original occupying family will reside in the dwelling unit before it changes occupancy and a new family moves in with different waste flow characteristics. Occupancy characteristics of dwelling units were

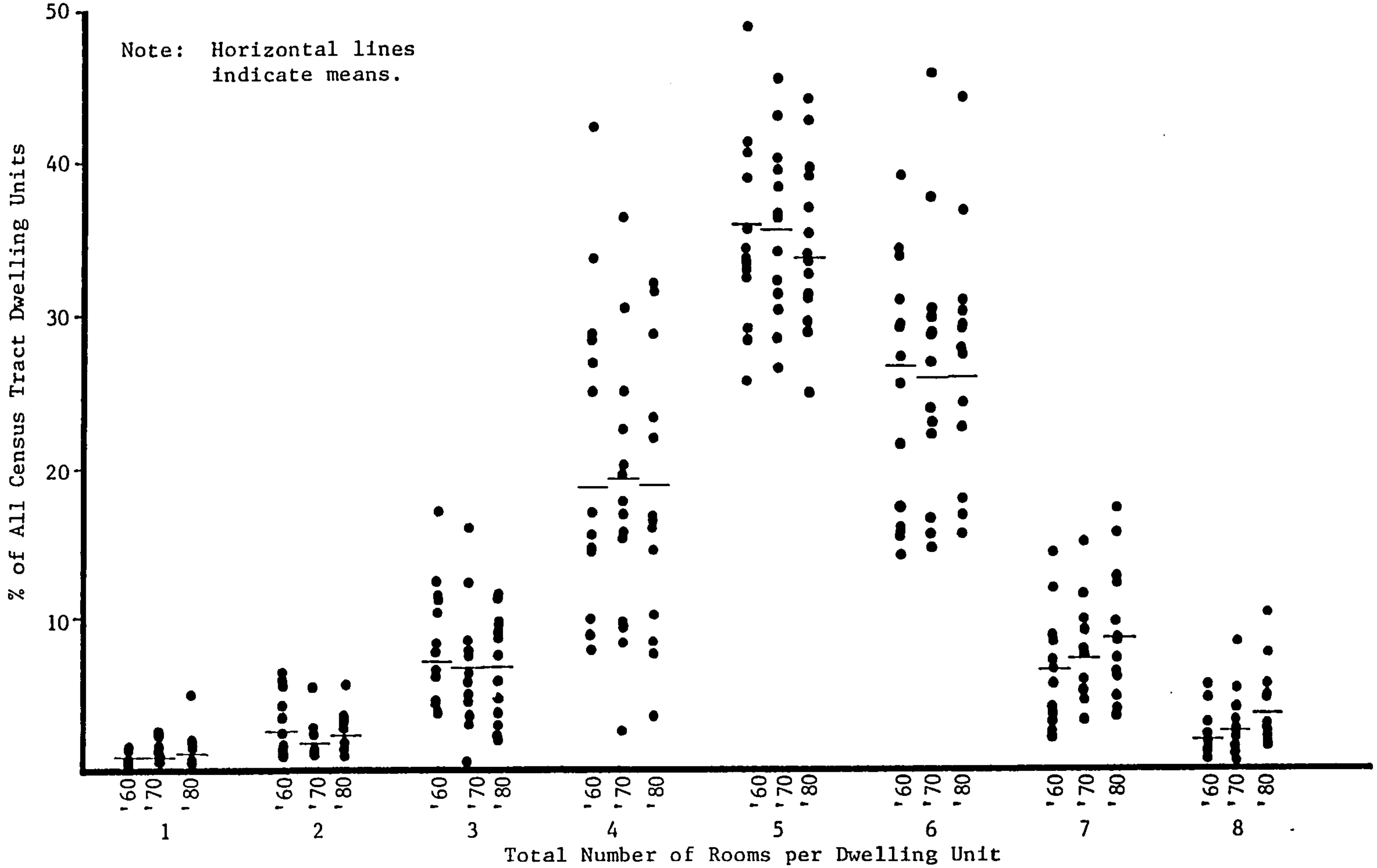


Figure 4.30 Percentage Distribution of Owner-Occupied Dwelling Units in Selected Tulsa, Oklahoma Census Tracts by Reported Number of Rooms in 1960, 1970 and 1980.

extracted from census data(16,17,18) and related to other demographic and housing variables by computing median years of occupancy prior to the census date (from data indicating the year householders moved into the units) for each of the fifteen census tracts for 1970 and 1980.

Median years of occupancy of owner-occupied dwelling units showed no relationship to median reported values of owner-occupied dwelling units during either 1970 or 1980. This suggests that income, as measured by housing value, bears little relationship to length of occupancy when owner-occupied units are involved. This relationship is graphically depicted in Figure 4.31. However, significant declines in the percentages of housing units which are owner-occupied were found to occur as median ages of census tract housing increased. In other words, as the neighborhoods aged, an increasing percentage of the housing units were occupied by renters. This relationship is apparent in the data presented from the 1960, 1970, and 1980 censuses in Figure 4.32. The percentage of owner-occupied units, which was near 100% immediately following construction, declined logarithmically to approximately 65% owner occupancy as the dwelling units reached about forty years of age.

As the dwelling units aged, significant changes in age composition and household population densities also occurred. In general, as the age of neighborhood housing increased so did the median age of the occupants. This increase in dwelling unit and occupant ages was accompanied by a general increase in length of occupancy. This trend is reflected in Figure 4.33 which relates median years of occupancy to median age of housing units for the fifteen census tracts as reported in the 1970 and 1980 censuses. It should be noted in that figure that 1980

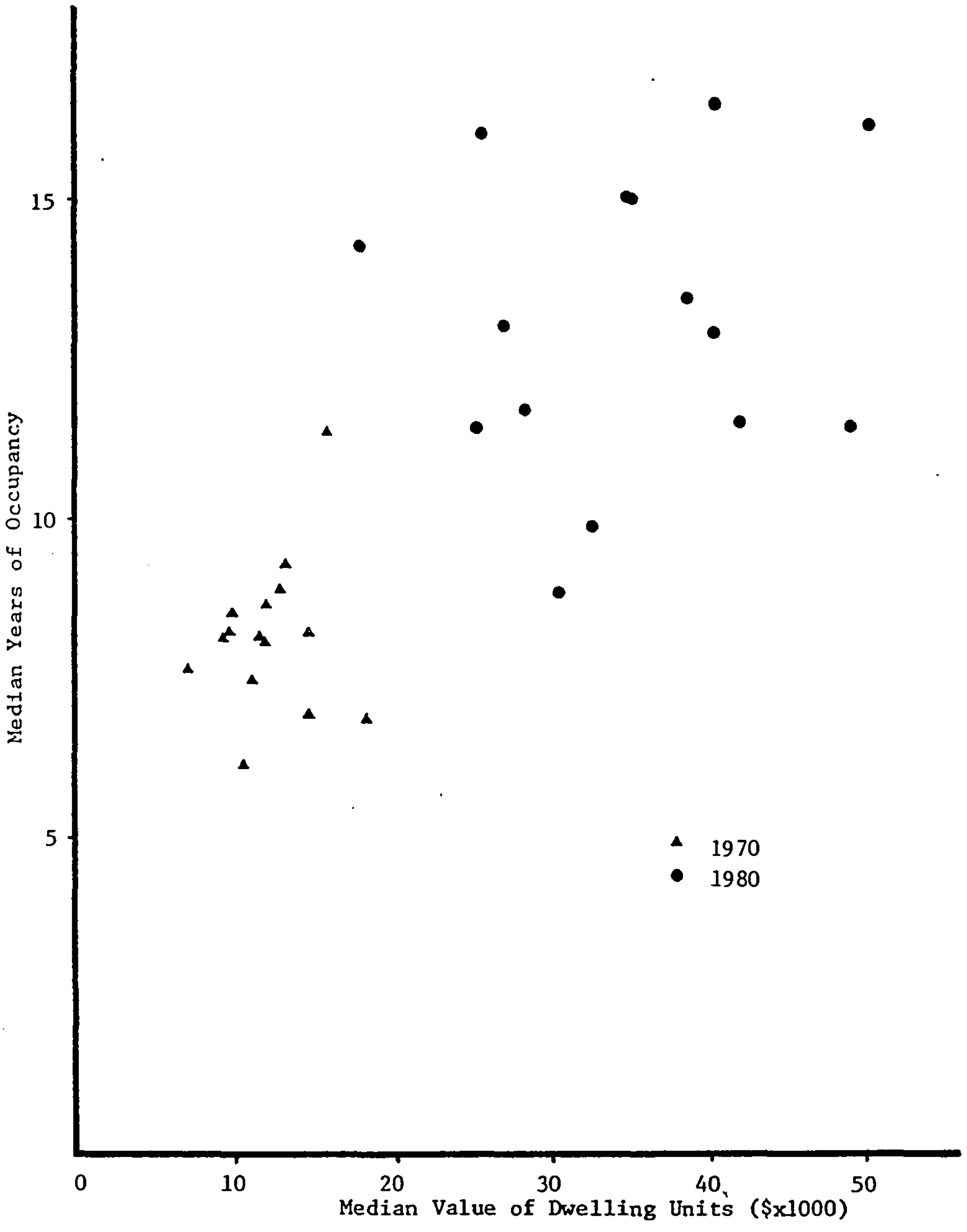


Figure 4.31 Median Value of Dwelling Units Versus Median Years of Occupancy for Owner-Occupied Dwelling Units in Selected Tulsa, Oklahoma Census Tracts in 1970 and 1980.

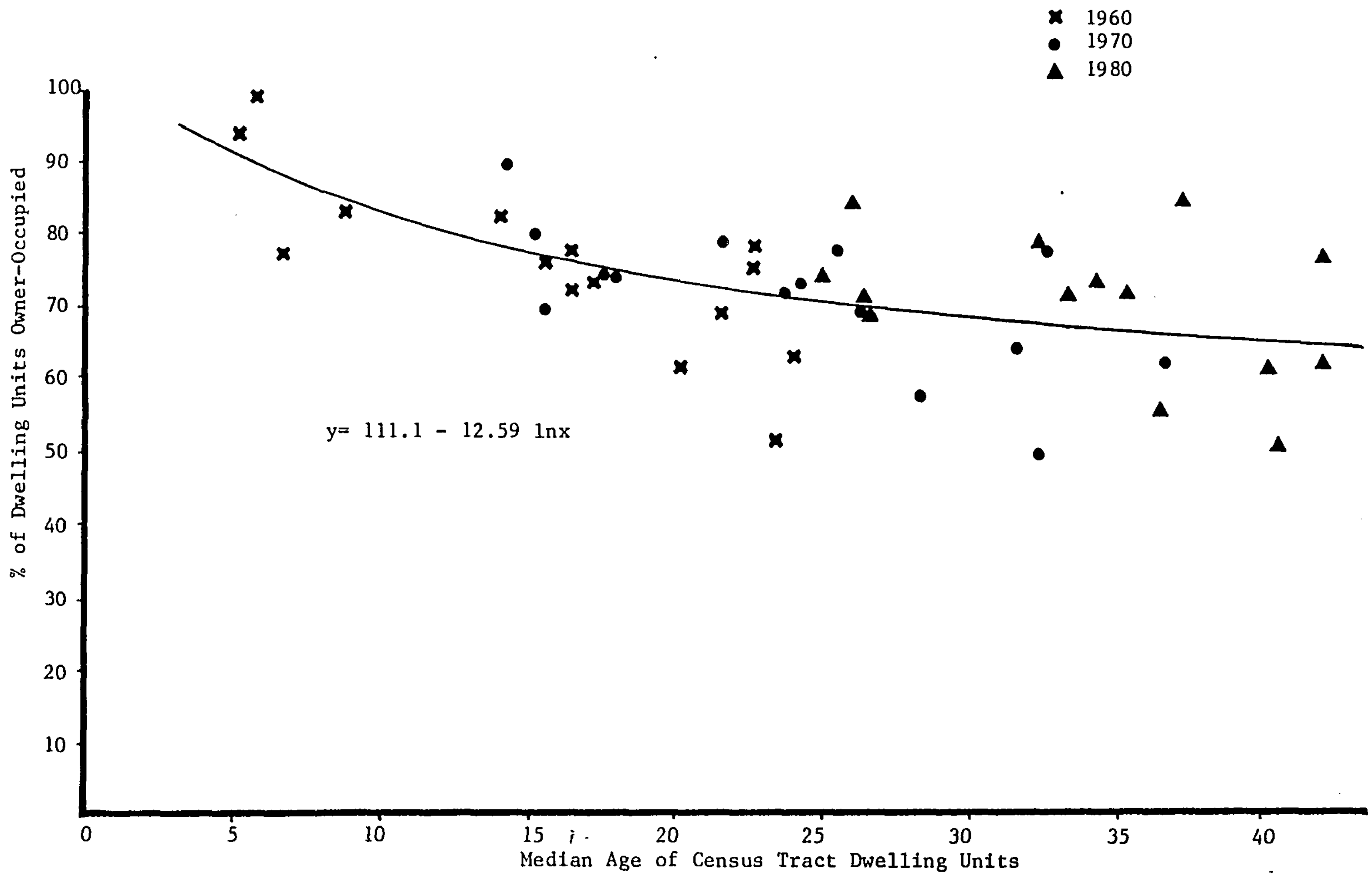


Figure 4.32 Median Age of Census Tract Dwelling Units Versus Percentage of Units Reported Owner-Occupied for Selected Tulsa, Oklahoma Census Tracts, 1960, 1970 and 1980.

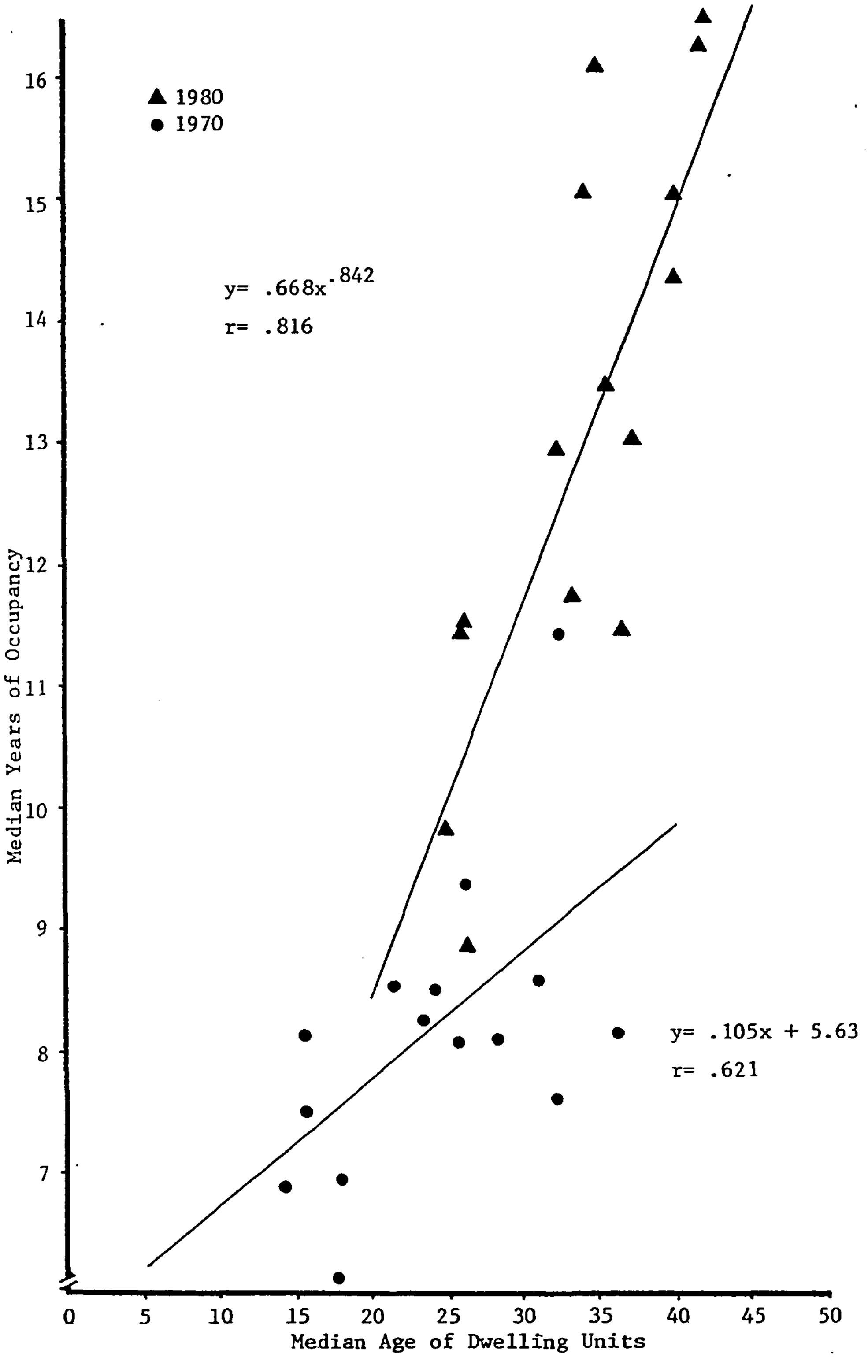


Figure 4.33 Median Age of Dwelling Units Versus Median Years of Occupancy for Owner-Occupied Dwelling Units in Selected Tulsa, Oklahoma Census Tracts in 1970 and 1980

census data reflect even greater neighborhood stability (in terms of less frequent changes in occupancy) than did the 1970 census data, perhaps due to changing economic conditions such as higher interest rates and rapidly inflating housing costs which were manifested in a lower housing turnover rate.

Increasing length of census tract housing unit occupancy is compared with percentages of the census tract populations sixty-five years of age and older in Figure 4.34. This figure reflects a tendency toward greater lengths of occupancy in census tracts with higher percentages of elderly persons which coincidentally corresponds with increasing dwelling unit age. The trend was more pronounced in 1980 census data than in 1970 data but is clearly evident in both. The opposite effect, i.e., the inverse relationship between census tract residents nineteen years of age and younger and median years of dwelling unit occupancy, is depicted in Figure 4.35 for the 1970 and 1980 censuses. This figure additionally supports the scenerio of a neighborhood aging process characterized by increasing percentages of elderly individuals and decreasing percentages of children.

The overall trend of aging population as housing ages is more clearly depicted in Figure 4.36 which is based upon 1960, 1970 and 1980 census data for the fifteen tracts. It is apparent in this figure that, at the time of initial construction, the percentage of the population sixty-five years of age and over is near zero but increases as a power function to an average of just over twenty-three percent when tract housing reaches forty years of age. The inverse nature of this relationship is evident in Figure 4.37 also based upon 1960, 1970 and

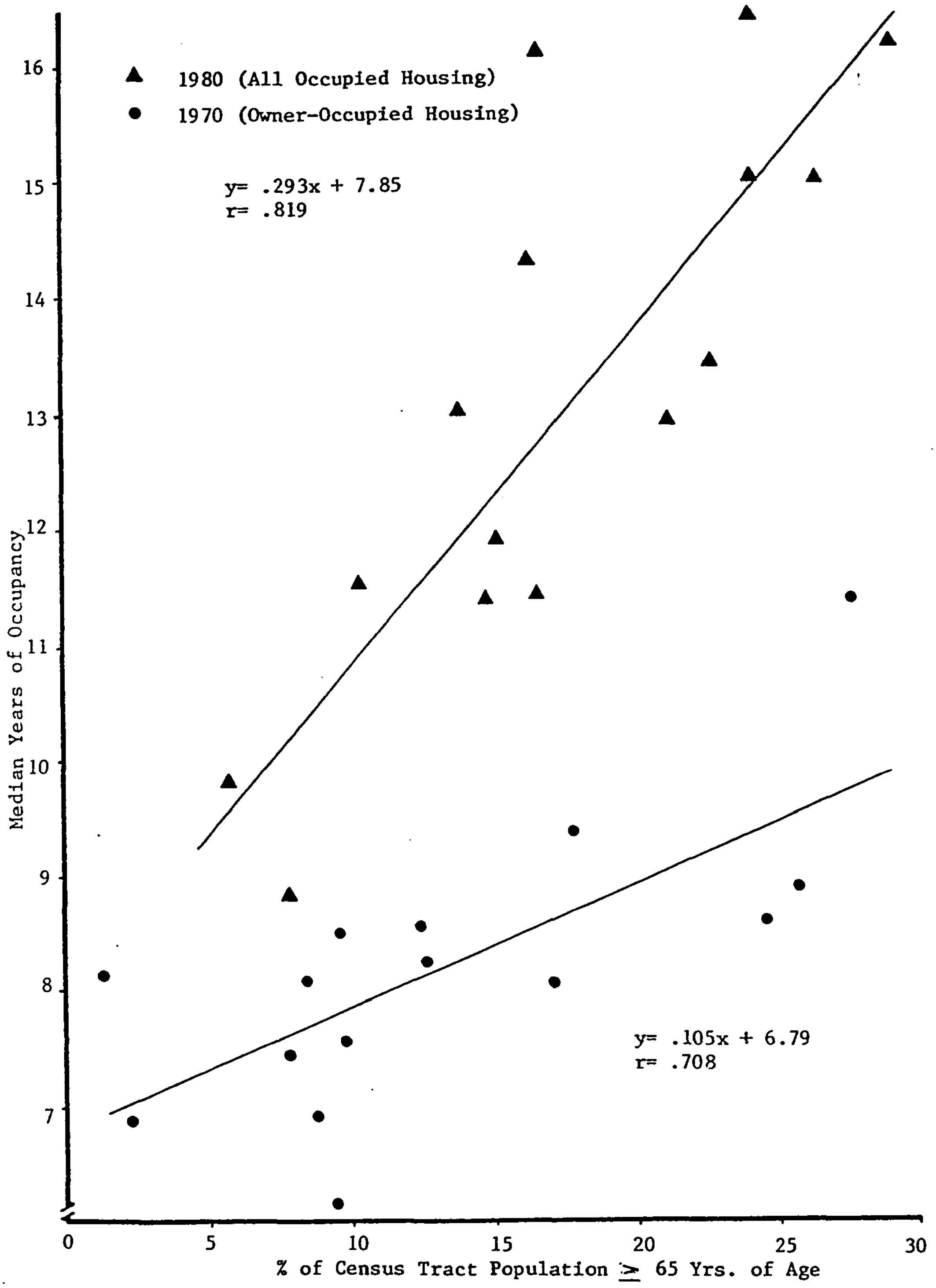


Figure 4.34 Percentage of Population Equal to or Greater than Sixty-five Years of Age Versus Median Years of Occupancy for Dwelling Units in Selected Tulsa, Oklahoma Census Tracts in 1970 and 1980.

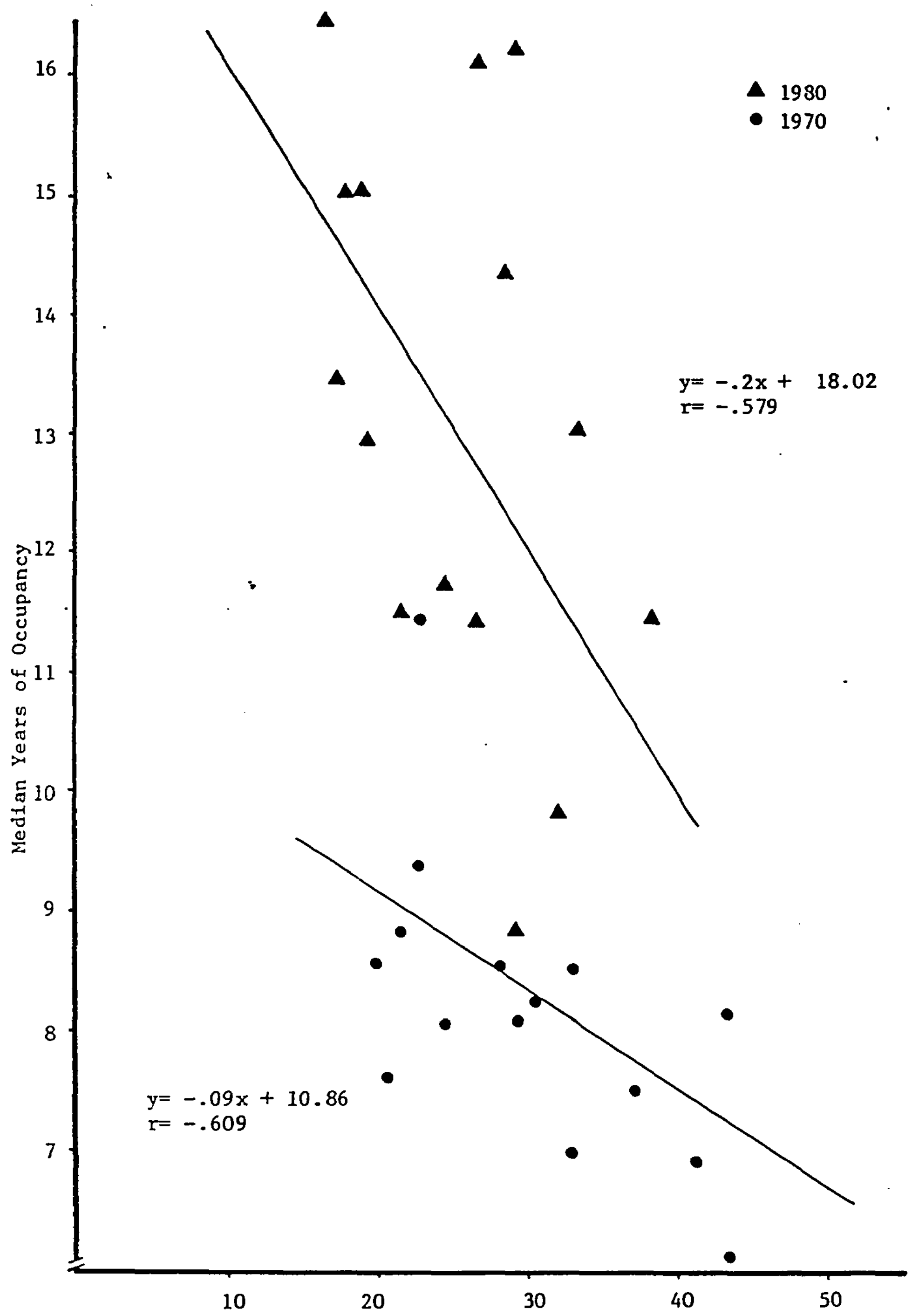


Figure 4.35 Percentage of Population Equal to or Less Than Nineteen Years of Age Versus Median Years of Occupancy for Dwelling Units in Selected Tulsa, Oklahoma Census Tracts in 1970 and 1980.

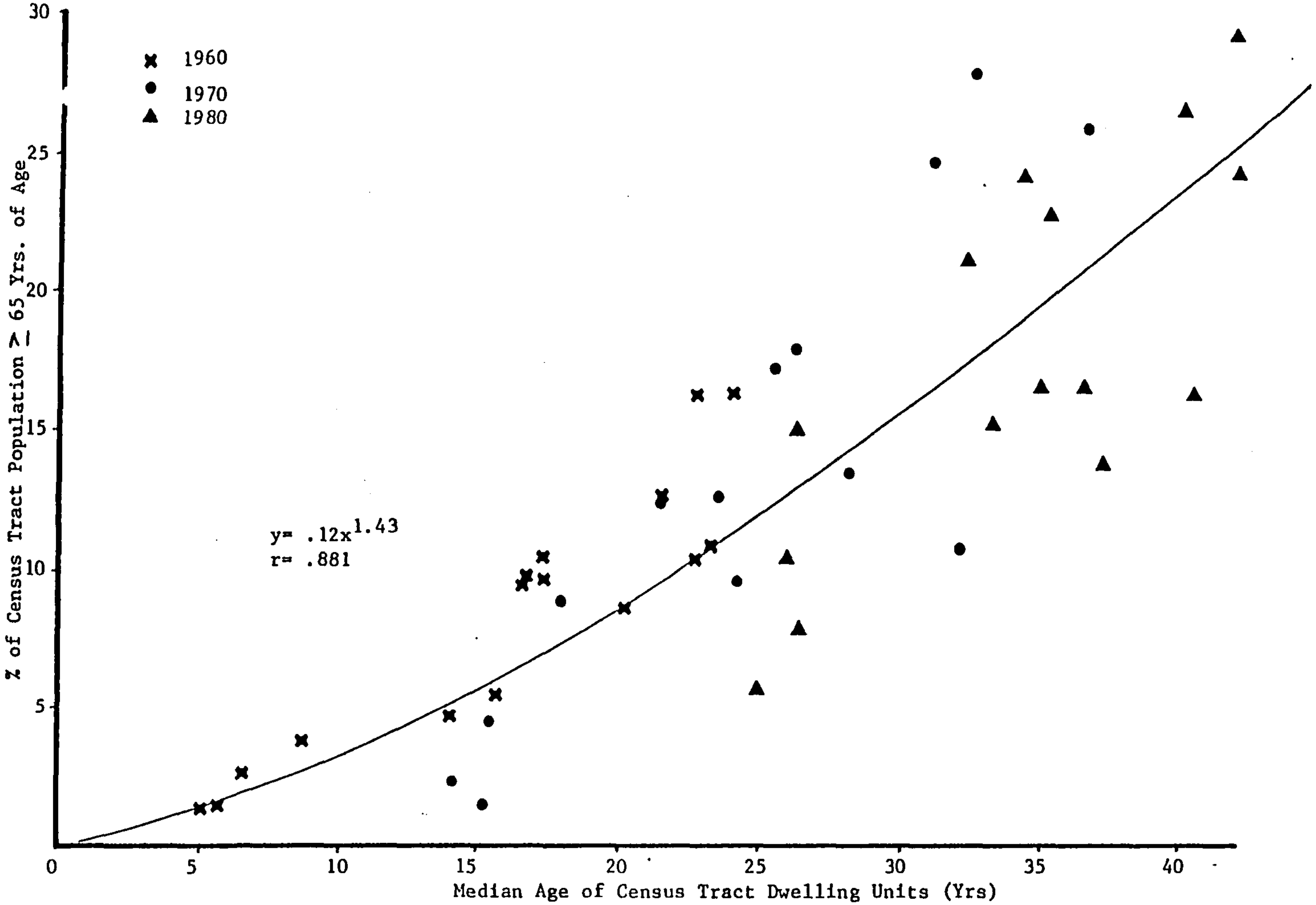


Figure 4.36 Median Age of Census Tract Dwelling Units Versus Percentage of Population Equal to or Greater Than Sixty-five Years of Age in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

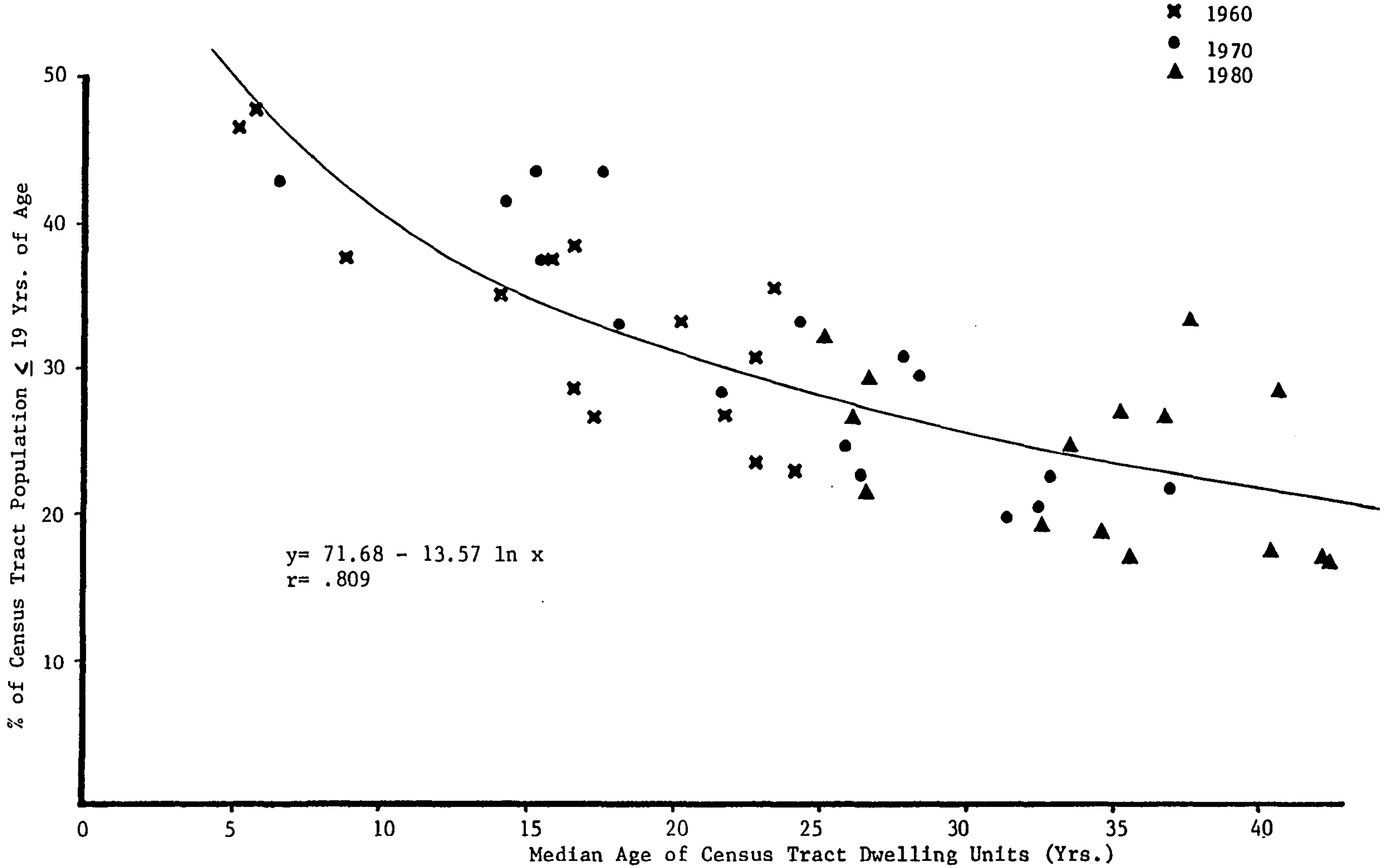


Figure 4.37 Median Age of Census Tract Dwelling Units Versus Percentage of Population Equal to or Less Than Nineteen Years of Age in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

1980 data. In that figure the percentage of children residing in tract dwelling units declines in a near logarithmic manner from between fifty and sixty percent upon initial occupancy of the new dwelling units to just over twenty percent when the units reach forty years of age.

Comparisons of the percentages of census tract dwelling units occupied by the same families 1) less than ten years, 2) ten to twenty years, and greater than twenty years at the times of the 1970 and 1980, censuses as compared with the median age of census tract housing units, are shown in Figures 4.38, 4.39 and 4.40, respectively. Although the curves shift slightly between the two censuses for each of these three categories, the same general trends are evident for both censuses. That is, the percentages of dwelling units occupied less than ten years by the same family decrease as the average ages of the dwelling units increases. The percentages of families occupying dwelling units between ten and twenty years also declines, although less dramatically, and the percentages of families occupying dwelling units longer than twenty years rises significantly as the median ages of the dwelling units increase. With respect to the latter category, it is important to be cognizant of the fact that a significant portion of the increase among relatively newer dwelling units, e.g. those 15 to about 25 years of age, is simply due to the growing number of units reaching 20 years of age and beyond and becoming capable of occupancy for longer than 20 years.

The overall scenario these data support is a trend of increasingly longer dwelling unit occupancy by the same family as the median age of the dwelling unit increases coupled with a general aging of the occupants, even though the units change occupying familes. This implies

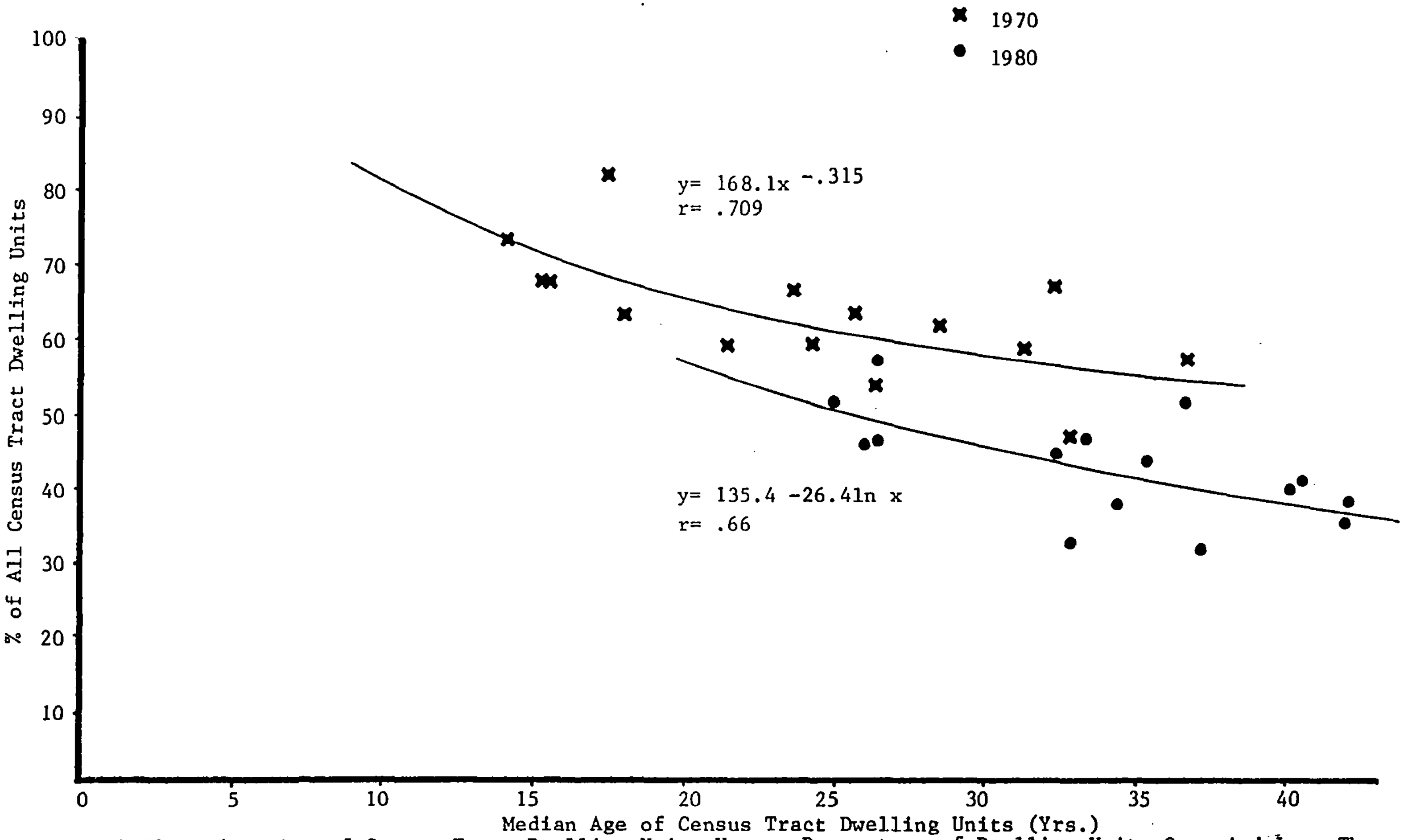


Figure 4.38 Median Age of Census Tract Dwelling Units Versus Percentage of Dwelling Units Occupied Less Than Ten Years by Current Occupant in Selected Tulsa, Oklahoma Census Tracts in 1970 and 1980.

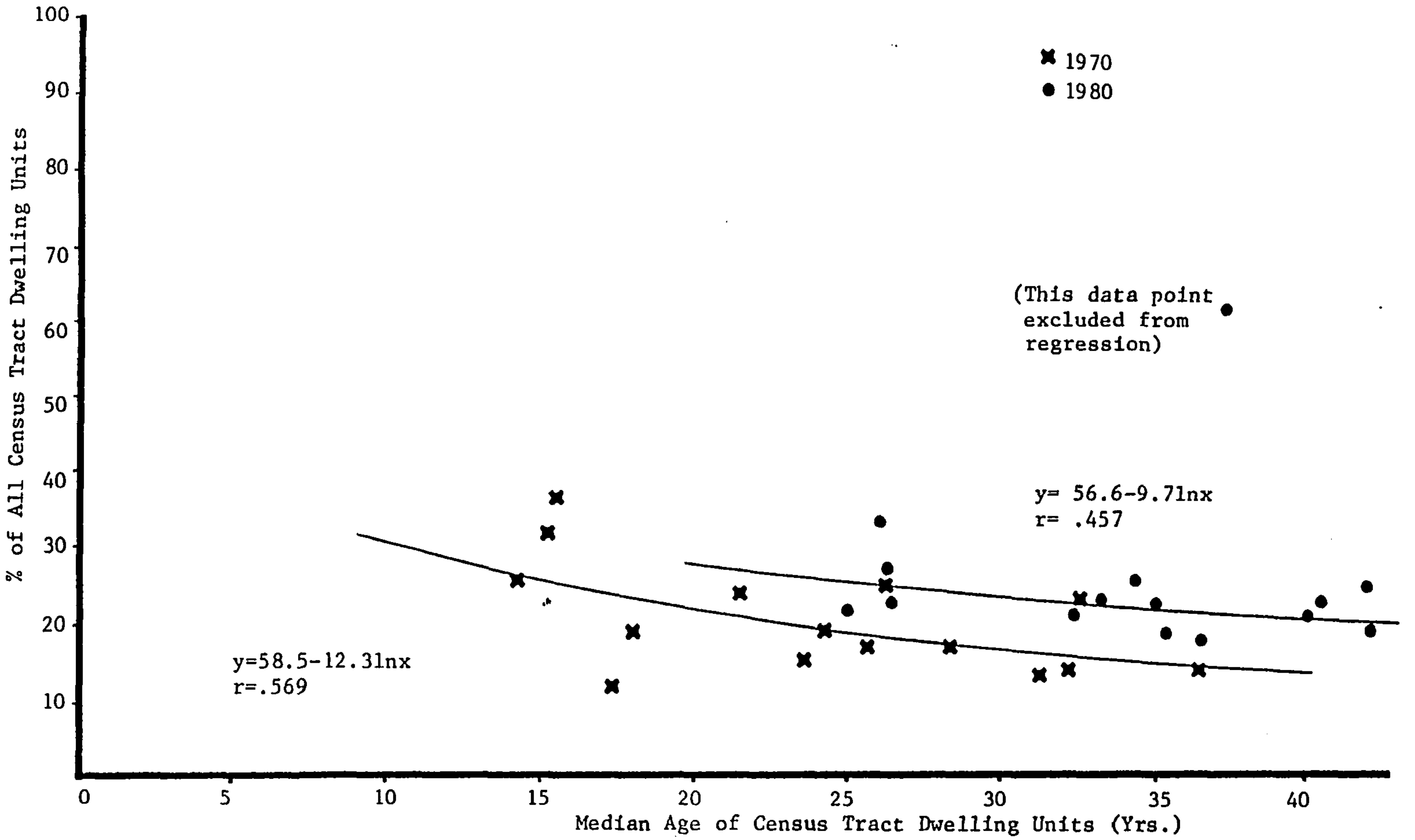


Figure 4.39 Median Age of Census Tract Dwelling Units Versus Percentage of Dwelling Units Occupied Between Ten and Twenty Years by Current Occupant in Selected Tulsa, Oklahoma Census Tracts in 1970 and 1980.

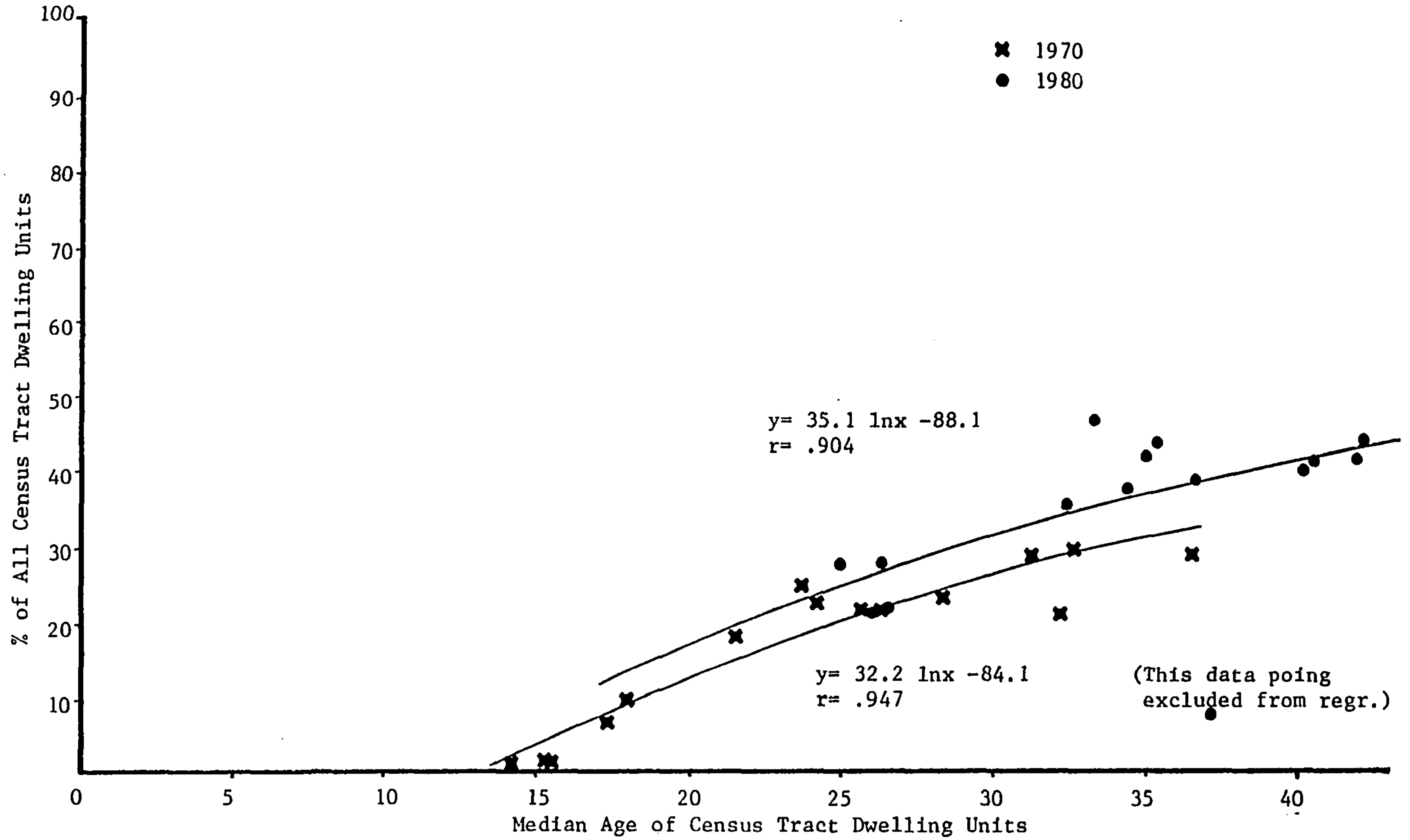


Figure 4.40 Median Age of Census Tract Dwelling Units Versus Percentage of Dwelling Units Occupied Longer Than Twenty Years by Current Occupant in Selected Tulsa, Oklahoma Census Tracts in 1970 and 1980.

that families moving into vacated dwelling units generally tend to fulfill the same demographic trends exhibited by the original occupants, including, especially, occupant aging as the dwelling unit ages.

Along with this tendency of the inhabiting population to age as the housing unit ages, a pronounced, nearly logarithmic decline in the population of owner-occupied housing units also occurs. The relationship between owner-occupied housing unit population and median age of housing is presented in Figure 4.41. It is apparent in that the figure that the average owner-occupied housing unit population for the tracts studied initially approached four persons per unit, declining steeply for several years, but becoming more gradual after the units reached thirty to forty years of age. This figure suggests that average housing unit population fell below three persons per unit as the units reached approximately twelve years of age but did not decrease below two persons per unit until the units were about thirty-five years old.

The data presented in Figure 4.41 are representative of census tract housing units exhibiting a median 5.1 rooms per dwelling unit. Presumably, larger dwelling units have the potential of larger household populations since, on the average, more space is available for additional occupants. It is apparent that the decline in household population with increasing dwelling unit age could easily mask any correlation between dwelling unit population density and dwelling unit size if units of different ages are included in the analysis. This may be a primary reason for the failure of attempts during this study and others to confirm statistically significant correlations between dwelling unit population densities and dwelling unit size, as well as

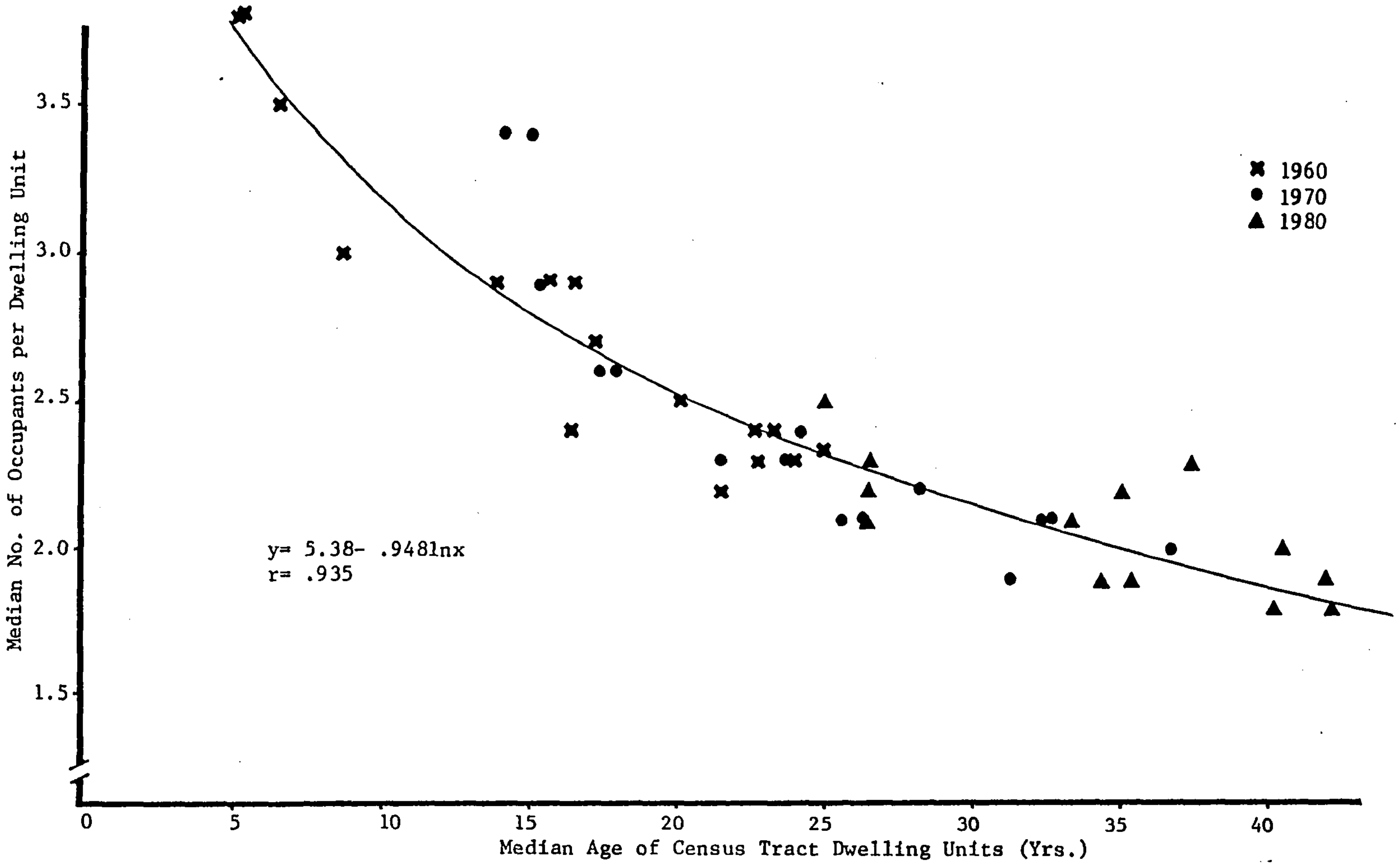


Figure 4.41 Median Age of Census Tract Dwelling Units Versus Median Number of Occupants per Unit in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

other measures such as value (see Figure 4.42). It is possible that statistically significant direct relationships between increasing dwelling unit size and increasing dwelling unit population could be identified for new housing units and/or housing units of approximately equivalent age. However, the strengths of these relationships would likely be reduced to some extent by variance introduced from considerations other than family size influencing decisions regarding the purchase of dwelling units. One such particularly significant influence is the tendency for individuals to purchase larger than needed dwelling units for increased tax advantages and for investment purposes.

Considerable additional understanding of the dynamics of neighborhood change, with respect to dwelling unit population density and age structure, can be gained by comparing changes in percentages of dwelling units with different population-age relationships. Gradual declines occur in the percentages of units occupied by three or more persons as the units age beginning with their initial construction. This corresponds to a gradual increase in the percentages of one and two person households, the latter of which begins to decrease after the dwelling units reach an average of about thirty years while the percentage of one person household continues to rise through forty-five years of age. Figures 4.43, 4.44 and 4.45 depict these density-age relationships for dwelling unit densities of one through six-plus persons. By employing linear and curvilinear regression techniques, mathematical expressions could be derived from which it was possible to construct a distribution table (Table 4.5), in five-year increments, of

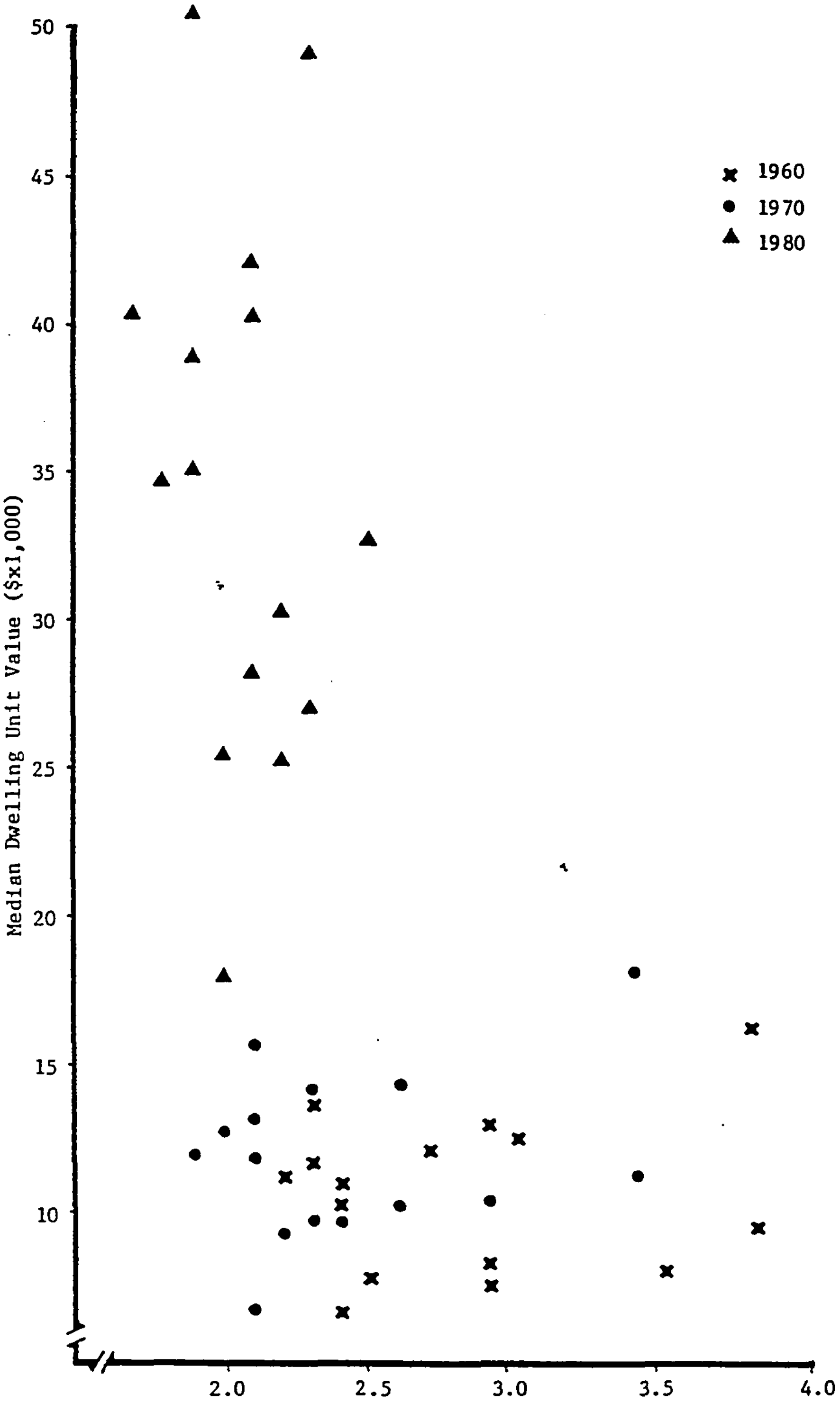


Figure 4.42 Median Number of Occupants per Owner-Occupied Dwelling Unit Versus Median Dwelling Unit Value in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980

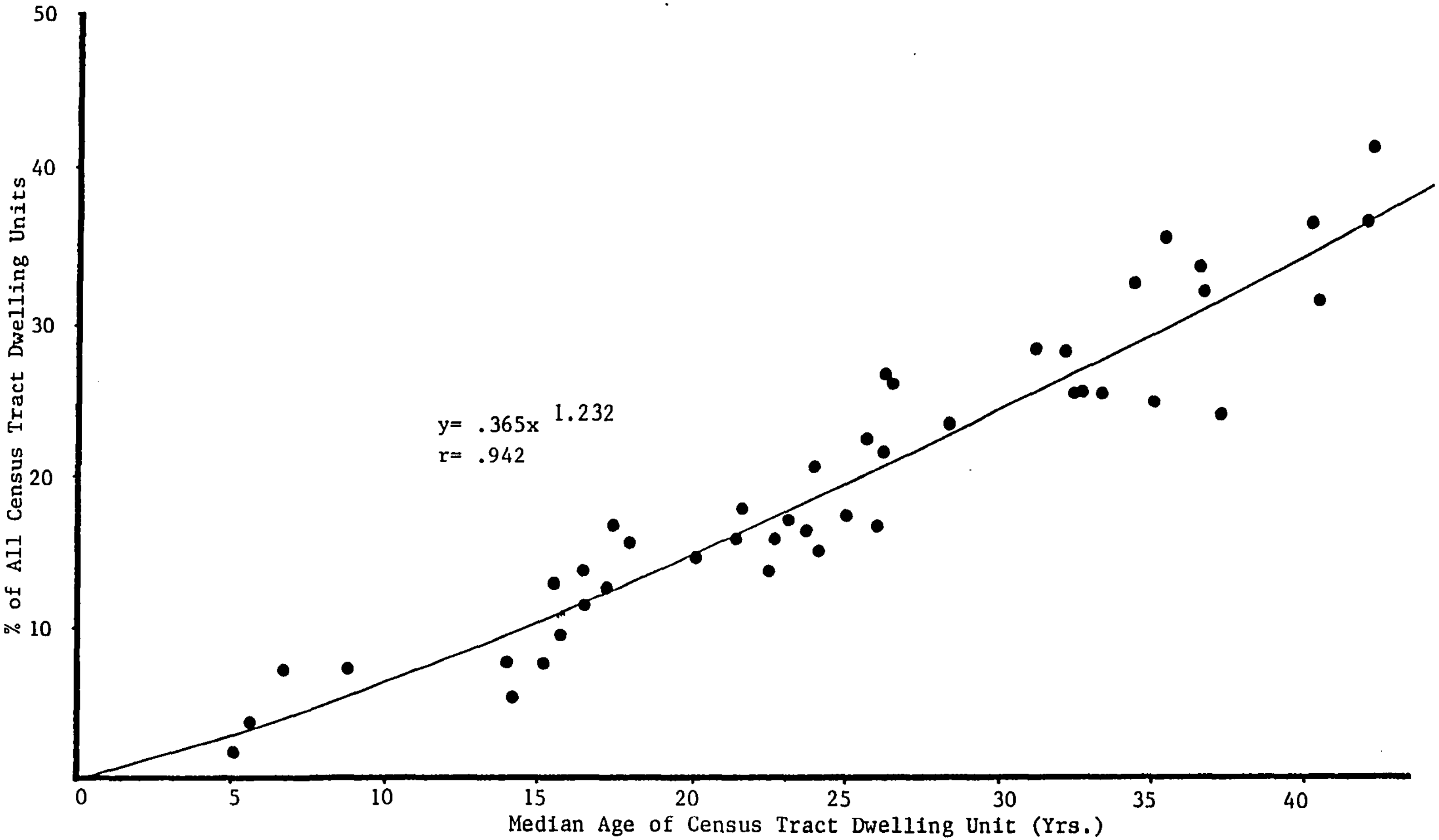


Figure 4.43a Median Age of Census Tract Dwelling Units Versus Percentage of Units with One Occupant in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

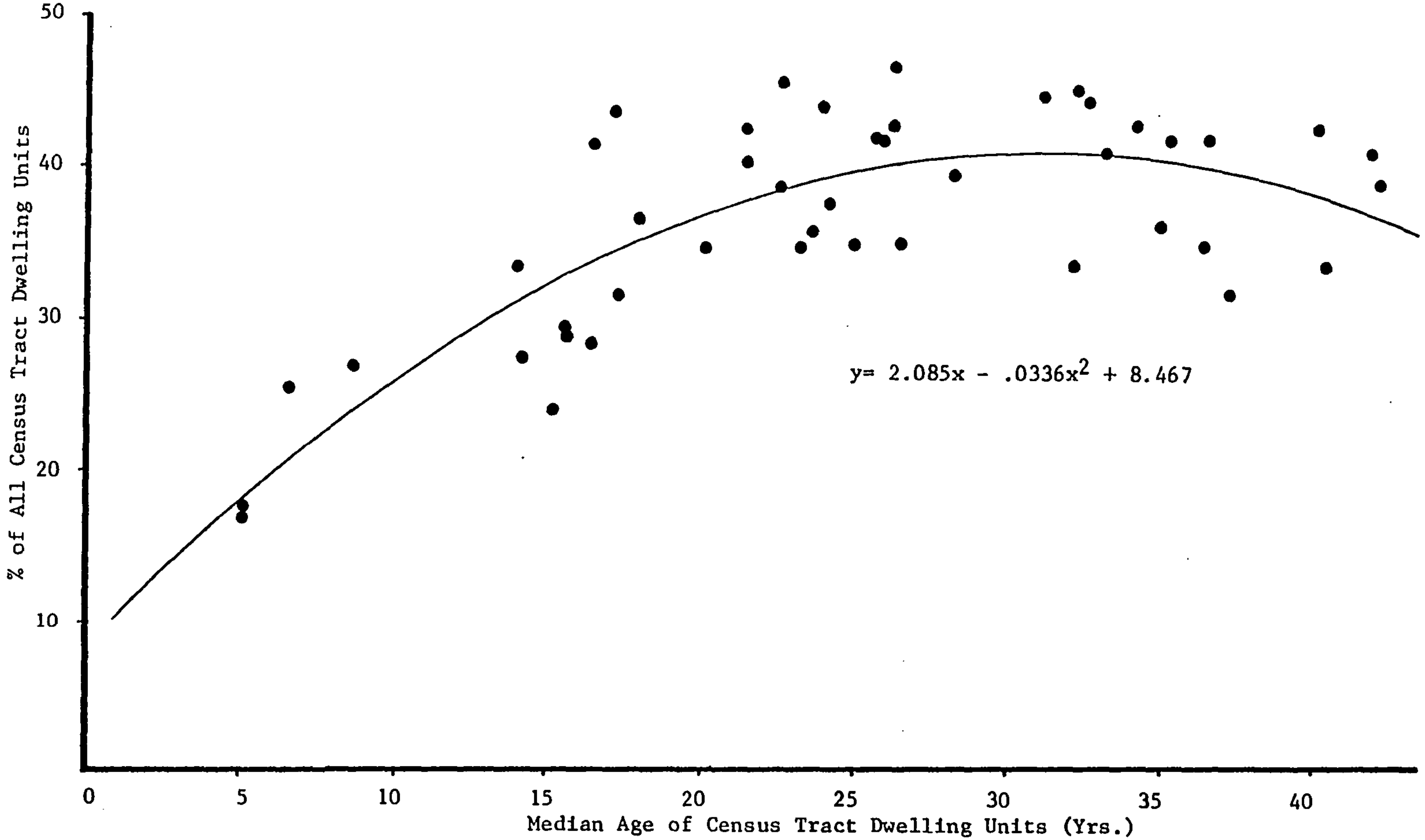


Figure 4.43b Median Age of Census Tract Dwelling Units Versus Percentage of Units with Two Occupants in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

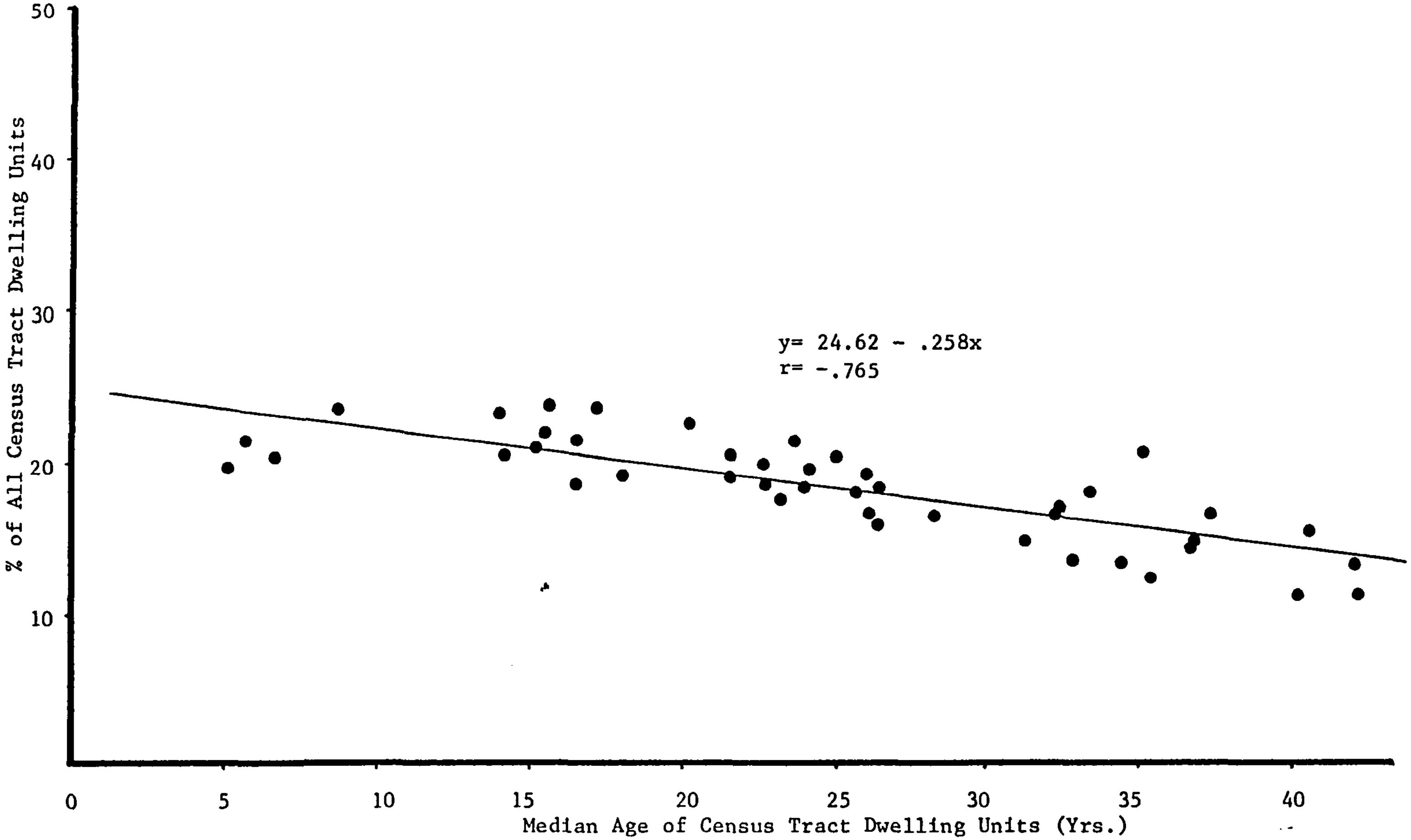


Figure 4.44a Median Age of Census Tract Dwelling Units Versus Percentage of Units with Three Occupants in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

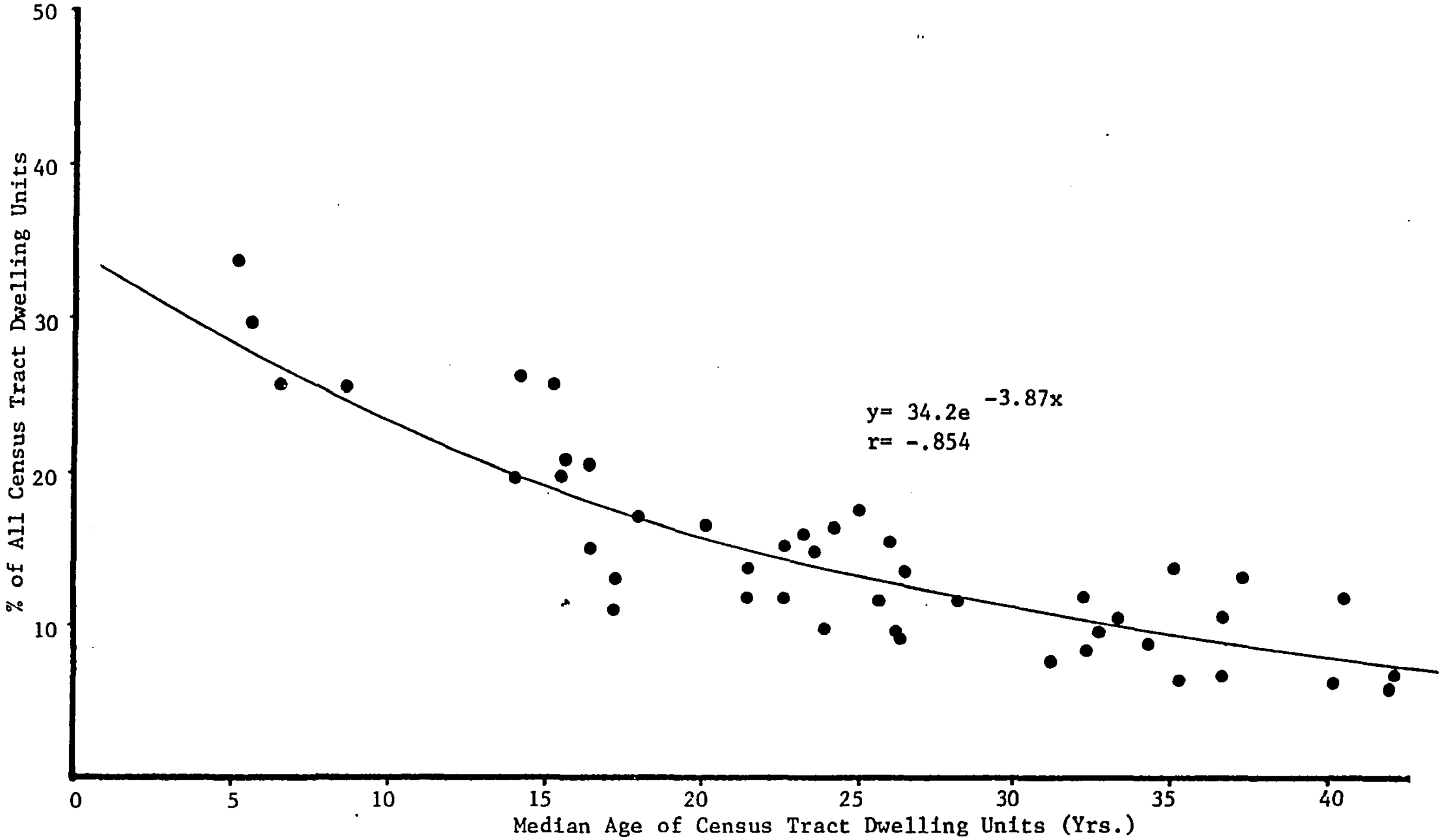


Figure 4.44b Median Age of Census Tract Dwelling Units Versus Percentage of Units with Four Occupants in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

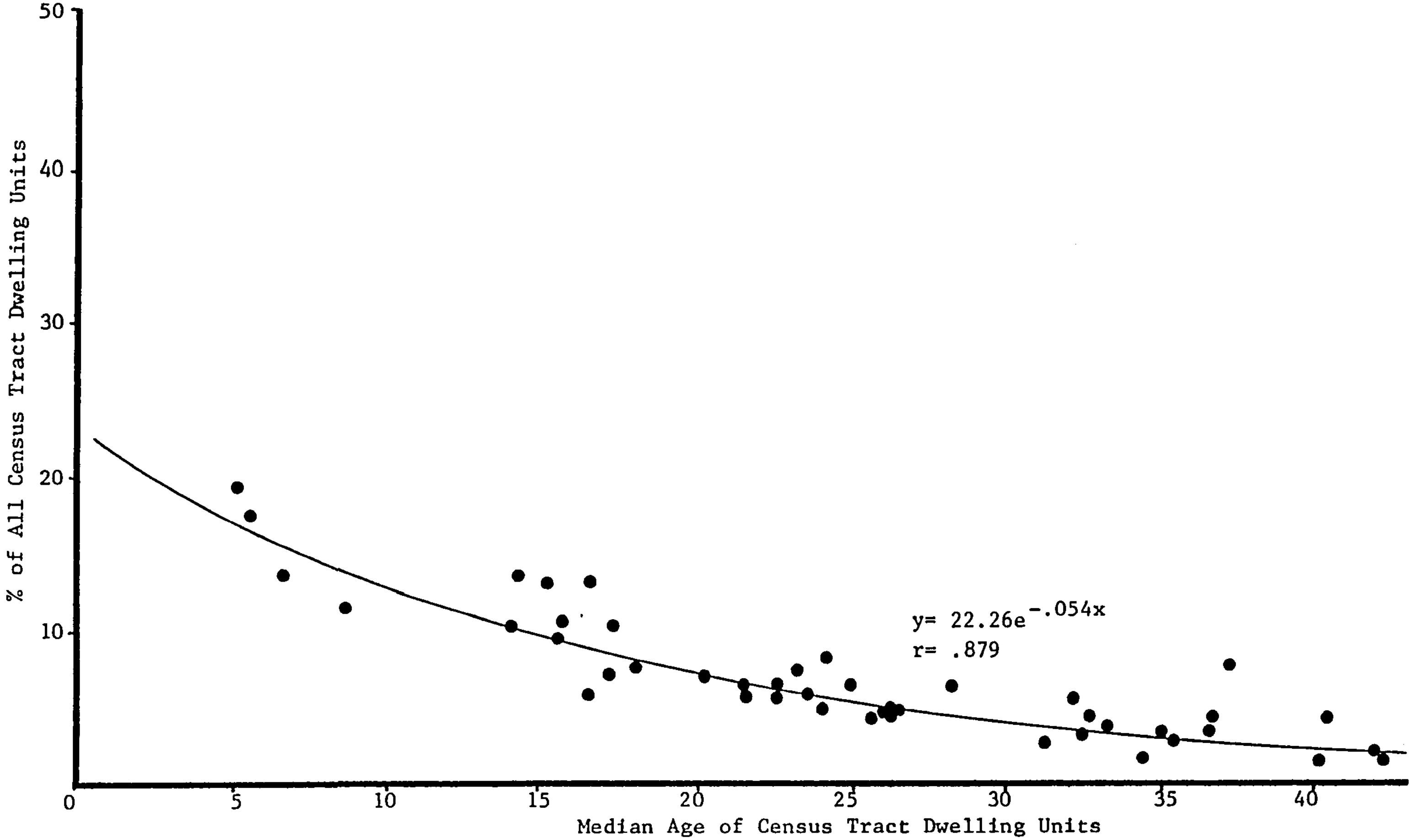


Figure 4.45a Median Age of Census Tract Dwelling Units Versus Percentage of Units With Five Occupants in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

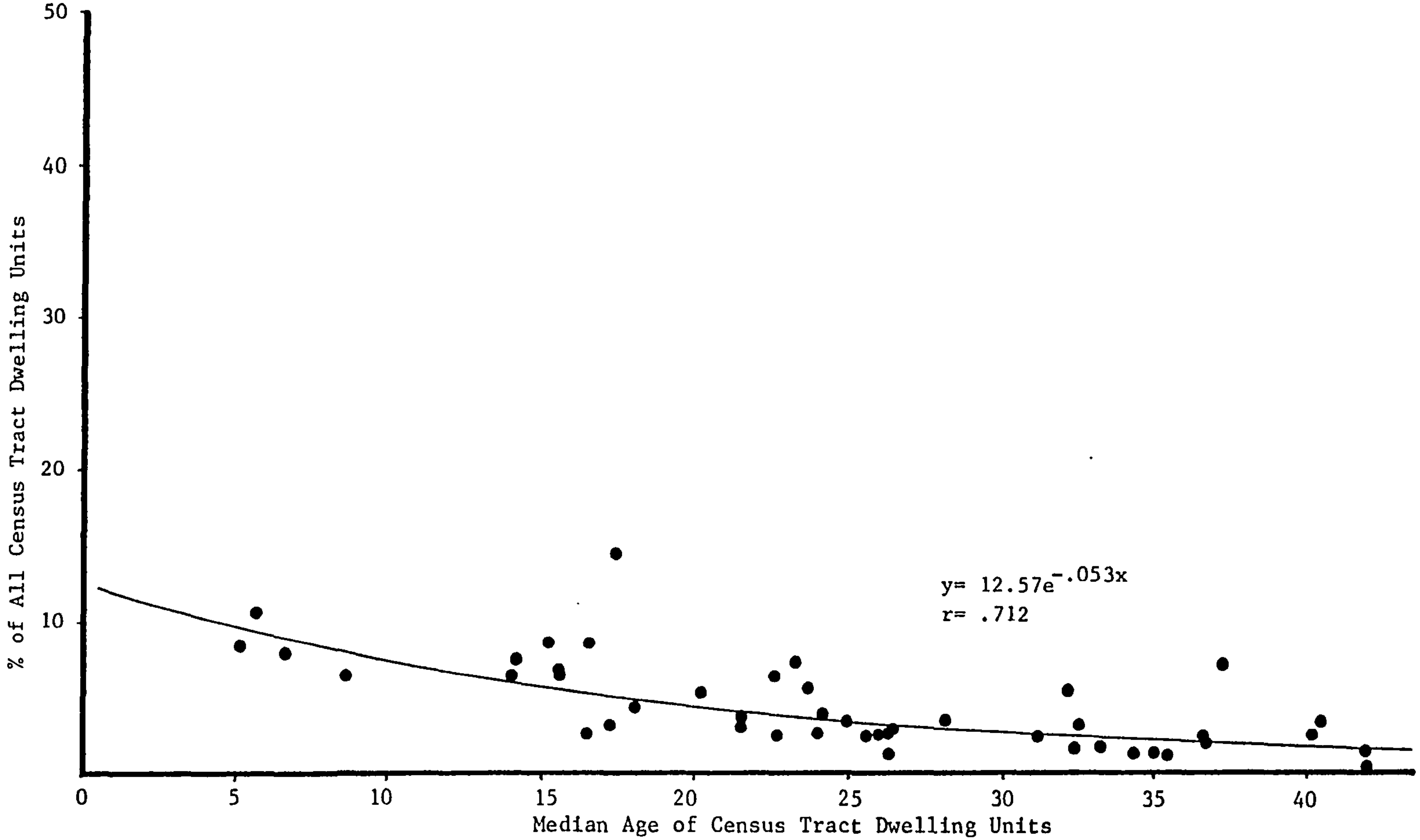


Figure 4.45b Median Age of Census Tract Dwelling Units Versus Percentage of Units with Six of More Occupants in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

## TABLE 4.5

## AVERAGE PERCENTAGE DISTRIBUTION OF PERSONS PER DWELLING UNIT BY AGE OF UNIT FOR SELECTED TULSA, OKLAHOMA CENSUS TRACTS [1]

| AGE OF DWELLING (years) | NUMBER OF PERSONS PER DWELLING UNIT | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6+ | TOTAL |
| 1 | 0.4 | 10.5 | 24.4 | 32.9 | 21.1 | 11.9 | 101.2 |
| 5 | 2.6 | 18.0 | 23.3 | 28.2 | 17.0 | 9.6 | 98.7 |
| 10 | 6.2 | 26.0 | 22.0 | 23.2 | 12.9 | 7.4 | 97.7 |
| 15 | 10.3 | 32.2 | 20.8 | 19.1 | 9.8 | 5.7 | 97.9 |
| 20 | 14.6 | 36.7 | 19.5 | 15.8 | 7.5 | 4.4 | 98.5 |
| 25 | 19.3 | 39.6 | 18.2 | 13.0 | 5.7 | 3.4 | 99.2 |
| 30 | 24.1 | 40.8 | 16.9 | 10.7 | 4.4 | 2.6 | 99.5 |
| 35 | 29.1 | 40.2 | 15.6 | 8.8 | 3.3 | 2.0 | 99.0 |
| 40 | 34.4 | 38.1 | 14.3 | 7.3 | 2.5 | 1.5 | 98.4 |
| 45 | 39.8 | 34.2 | 13.0 | 6.0 | 1.9 | 1.2 | 96.1 |

[1] Estimates calculated by predictive regression equations based upon 1960, 1970 and 1980 census data for selected Tulsa, Oklahoma census tracts. See text and Figures 4.43, 4.44 and 4.45.

persons per dwelling unit versus age of dwelling units. The additive percentage of dwelling units by population density for each five-year age category totaled very nearly 100% utilizing this method.

From this distribution it is possible to reconstruct a typical neighborhood change scenario which begins with approximately ninety percent of newly constructed dwelling units being occupied by families with one or more children of varying ages. The children, as well as probably some of the adults, immediately begin to leave home, primarily as the children mature, but in some cases as a result of separations and divorces of parents, deaths of family members, etc. As housing turns over, the greastest number of the new occupying families, approximately one-third, consists of four individuals, with about one-fourth being three-member families and one-fifth being five-member families. About twelve percent, or approximately one in six, contain six or more family members. The decline in the number of children continues, at a gradually decreasing rate, during the entire forty-five year life span studied. Although length of occupancy data indicate considerable turnover of housing occurs during this period, the continued decline in these rates strongly suggests that families fitting the same general demographic and age categories, as well as, probably, similar lifestyles, move into the area to replace vacating families and continue the trend toward declining family size.

As the dwelling units reach approximately thirty years of age, the increase in the number of two-member households, which has resulted primarily from children moving away from home, peaks and gradually begins to decline, probably as a result of the separation, divorce and/or death of one of the remaining parents in the typical family. The data suggest that the rate of decline in two-member households accelerates gradually after dwelling units reach thirty-five to forty years of age with a corresponding gradual acceleration in the rate of increase of one-member households mainly representing the remaining spouse of the original parental pair.

Distributions of percentages of dwelling units with children (one to nineteen years of age) and percentages of households with persons 65 years of age and older, as compared with average dwelling unit age, corroborate this social change scenario of aging neighborhoods.

The implication of this scenario for design of individual sewage treatment facilities is primarily that the facilities should be designed for treatment of maximum influent waste loadings at the time of initial installation (for new housing) since the probable trend is toward declining household populations and, subsequently, declining wastewater flows. However, the decline in dwelling unit population is accompanied by a change in the age composition of the typical family which is marked by an increase in average age resulting from the decline in the number of children coupled with a generally consistent adult population. Since water consumption data indicate a normally greater per capita waste flow from teenagers than from adults and children, the rate of waste flow decline will be lessened, somewhat, by the increase in the percentage of teenagers in the typical family.

Another important consideration for design model construction is the recent decrease in the family size of initial occupying households as compared with the longitudinal data used in this analysis. For example, initial occupying households in the forgoing analysis were those typical of the late 1950's and were somewhat larger than today's smaller families. Adjustments to account for this change are discussed in subsequent sections detailing the design model assumptions.

## Lagoon Design Computer Model

The computer design model for onsite residential lagoons based upon the relationships developed during this research is written in M Basic for the Osborne Executive Portable Computer. It is easily adaptable to run on the IBM PC XT (modified copy available) by changing the page control character on line 100 of the program from (26) to (12). The model requires a 12 x 4 data matrix containing monthly evaporation, rainfall and runoff coefficients. The matrix filename is B:PPCTEVAP.DA.

By altering key local climatic variables, the model can be adapted for use in other geographic locations (provided demographic change and seepage assumptions are assumed to be acceptable for the area in question). Variables which require changing in this matter are contained in program lines 650 through 710 and include median annual rainfall, ninety-five percent annual rainfall probability, five percent annual rainfall probability, median annual pan evaporation rate, annual pan evaporation rate for five percent rainfall year, annual pan evaporation rate for ninety-five percent rainfall year, and the local lake evaporation coefficient.

The model assumes a design life of twenty-five years and a total facility depth of seven feet based upon a normal water depth of five feet and a two-foot dike freeboard. At the beginning of each program run the user is given the option of reviewing a brief explanation of the program's theory, methods of calculation and capabilities. Required keyboard inputs include the total number of dwelling unit rooms (based upon the census definition which excludes half rooms, porches, bathrooms, hallways, etc.), the desired inside dike slope (either 3:1 or 2.5:1), and the lagoon depth below grade, which is necessary for the determination of seepage rates. After the keyboard entries are made, the program begins water balance computations with internally controlled iterations attempting to achieve an optimum five-foot operating depth, if possible. The design is increased or decreased in one-foot bottom dimension increments to raise or lower operating depth, as needed. The minimum bottom design default dimension is six by six feet (thirty-six square feet) which is based upon the assumed minimal possible construction size using a small dozer.

Once the optimum design, within the user-defined constraints of slope and below grade depth, has been determined and the optimum design established, the user is given the option of requesting a printed copy of the design results which includes a twenty-five year monthly water balance for the facility showing all gains and loses for the five major water balance components of influent, precipitation, precipitation runoff, evaporation, and seepage. The average monthly operating depth is also printed out.

The user is subsequently given the option of performing a stress analysis on the lagoon's design capacity to assess the potential for system overflow or the development of unacceptably low operating conditions. The stress simulations include three separate analyses, climatic stress, excessive population density, and reduced seepage rates which can be selected seperately or jointly for inclusion. During climatic stress simulation, rainfall excess equivalent to the twenty-year rainfall exceedance (twenty-five percent rainfall probability level; one year in twenty would normally receive more rainfall) is applied in the second year of facility operation which would be the critical year for facility overflow. In addition, a twenty-year annual drought (five percent rainfall probability level, one year in twenty normally has less rainfall) is applied in the twenty-fourth year of lagoon operation to assess the lagoons ability to maintain a sufficient (two-foot) minimum operating depth under drought conditions.

The second stress analysis simulation increases the household population density fifty percent above normal levels for the entire design life of the facility to simulate the fifty percent increase in influent flows which would result from an unusually large occupying family. The third stress simulation option reduces the facility's seepage rate for the entire design life of the facility to the lower ninety-five percent confidence band for all of the surveyed lagoon systems. The effect of this reduction is to increase operating depth to test the facility's ability to remain within it's two-foot freeboard under reduced seepage conditions.

By applying all three stress simulation options simultaneously, the facility can be stressed to an extreme limit, especially in terms

Figure 4.46 Onsite Residential Lagoon Design Model Printout with 25 Yr Water Balance .

```
                ONSITE RESIDENTIAL LAGOON DESIGN

INPUT DATA SPECIFIED:

     Number of Dwelling Unit Rooms:                6
     Inside Dike Slope:                          1:3.0
     Lagoon Depth Below Grade:                   4.0 FT.

MODEL ASSUMPTIONS:

     Design Life of Facility:                     25 Yrs.
     Total Facility Depth:                         7 Ft.
     Maximum Normal Water Depth:                   5 Ft.
     Dike Freeboard:                               2 Ft.
     Median Annual Rainfall:                    36.5 In.
     Median Annual Lake Evap.:                  48.8 In.
     Initial Water Depth:                          2 Ft.

DESIGN RESULTS:

     Maximum Normal Depth:                      4.12 Ft.
     Design Bottom Area:                          36 Sq. Ft.
     Design Bottom Dimensions:               6 x   6 Ft.
       (Bottom dimensions set to minimum allowable default size).
     Inside Dike (Top) Area:                    2304 Sq. Ft.
     Inside Dike Dimensions:                48 x  48 Ft.
     Water Surface Area @ 5 Ft.:                1296 Sq. Ft.
     Surface Dimensions @ 5 Ft.:            36 x  36 Ft.
     Surface BOD Load @ 5 Ft.:                  13.4 Lbs/ac/day
```

```
*************************** 25 YEAR MONTHLY WATER BALANCE ***********************
   MONTH      INFLUENT     PRECIP.     RUNOFF     EVAP.     SEEPAGE     DEPTH
    no.        gal/mo      gal/mo      gal/mo    gal/mo     gal/mo       ft.
   YEAR   1
      1          5810         322       1969       296          0        2.92
      2          5810         816        985       953       4974        3.97
      3          5810        1593        511      2140       5709        4.11
      4          5810        2294        399      2866       5672        4.11
      5          5810        2984        433      3063       6151        4.11
      6          5810        2655        307      3555       5267        4.11
      7          5810        1766        154      4120       3628        4.11
      8          5810        1788        182      3716       4059        4.11
      9          5810        2131        371      2774       5540        4.11
     10          5810        1897        606      2146       6150        4.11
     11          5810        1393        967      1376       6825        4.11
     12          5810        1047       1516       946       7424        4.12
   YEAR   2
      1          5804         938       1353       861       7264        4.12
      2          5804         910        919      1062       6668        4.11
      3          5804        1596        510      2144       5736        4.11
      4          5804        2294        399      2866       5667        4.11
      5          5804        2984        433      3062       6144        4.11
      6          5804        2655        307      3555       5261        4.11
      7          5804        1766        154      4120       3622        4.11
      8          5804        1788        182      3716       4053        4.11
      9          5804        2131        371      2774       5534        4.11
     10          5804        1897        606      2146       6144        4.11
     11          5804        1393        967      1376       6818        4.11
     12          5804        1047       1516       946       7418        4.12
   YEAR   3
      1          5793         938       1353       861       7253        4.12
      2          5793         910        919      1062       6657        4.11
      3          5793        1596        510      2144       5725        4.11
      4          5793        2294        399      2866       5656        4.11
      5          5793        2984        433      3062       6134        4.11
      6          5793        2655        307      3555       5250        4.11
      7          5793        1766        154      4119       3611        4.11
      8          5793        1788        182      3716       4042        4.11
      9          5793        2131        371      2774       5523        4.11
     10          5793        1897        606      2146       6133        4.11
     11          5793        1393        967      1376       6808        4.11
     12          5793        1047       1516       946       7407        4.12
   YEAR   4
      1          5778         938       1353       861       7238        4.12
      2          5778         910        919      1062       6642        4.11
      3          5778        1596        510      2144       5710        4.11
      4          5778        2294        399      2866       5641        4.11
      5          5778        2984        433      3062       6119        4.11
      6          5778        2655        307      3555       5235        4.11
      7          5778        1766        154      4119       3596        4.11
      8          5778        1788        182      3716       4027        4.11
      9          5778        2131        372      2774       5508        4.11
     10          5778        1897        606      2146       6118        4.11
     11          5778        1393        967      1376       6793        4.11
     12          5778        1047       1516       946       7392        4.12
   YEAR   5
      1          5759         938       1353       861       7220        4.12
      2          5759         910        919      1062       6623        4.11
      3          5759        1596        510      2144       5691        4.11
      4          5759        2293        399      2866       5622        4.11
      5          5759        2984        433      3062       6100        4.11
      6          5759        2654        307      3555       5216        4.11
      7          5759        1766        154      4119       3577        4.11
      8          5759        1788        182      3716       4008        4.11
      9          5759        2131        372      2774       5490        4.11
     10          5759        1897        606      2146       6099        4.11
     11          5759        1393        967      1376       6774        4.11
     12          5759        1047       1516       946       7373        4.12
   YEAR   6
      1          5737         938       1353       861       7197        4.12
      2          5737         909        919      1062       6601        4.11
      3          5737        1596        510      2144       5669        4.11
      4          5737        2293        399      2866       5600        4.11
      5          5737        2983        433      3062       6077        4.11
      6          5737        2654        307      3555       5194        4.11
      7          5737        1766        154      4119       3555        4.11
      8          5737        1788        182      3716       3986        4.11
      9          5737        2131        372      2774       5467        4.11
     10          5737        1897        606      2146       6077        4.11
     11          5737        1393        967      1376       6751        4.11
     12          5737        1047       1516       946       7351        4.12
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YEAR  7
   1      5712          938      1353       861      7172        4.12
   2      5712          909       919      1062      6575        4.11
   3      5712         1596       510      2144      5643        4.11
   4      5712         2293       399      2865      5574        4.11
   5      5712         2983       433      3062      6052        4.11
   6      5712         2654       307      3555      5169        4.11
   7      5712         1766       154      4119      3530        4.11
   8      5712         1788       182      3716      3961        4.11
   9      5712         2131       372      2774      5442        4.11
  10      5712         1897       606      2146      6051        4.11
  11      5712         1392       967      1376      6726        4.11
  12      5712         1047      1516       946      7325        4.12
YEAR  8
   1      5684          938      1353       861      7144        4.12
   2      5684          909       919      1062      6547        4.11
   3      5684         1596       511      2144      5615        4.11
   4      5684         2293       399      2865      5546        4.11
   5      5684         2983       433      3062      6024        4.11
   6      5684         2654       307      3555      5141        4.11
   7      5684         1766       154      4119      3502        4.11
   8      5684         1788       182      3715      3933        4.11
   9      5684         2131       372      2774      5414        4.11
  10      5684         1897       606      2146      6023        4.11
  11      5684         1392       967      1376      6698        4.11
  12      5684         1047      1516       946      7297        4.12
YEAR  9
   1      5654          937      1353       861      7113        4.12
   2      5654          909       919      1062      6517        4.11
   3      5654         1895       511      2144      5585        4.11
   4      5654         2293       399      2865      5516        4.11
   5      5654         2983       433      3062      5993        4.11
   6      5654         2654       307      3555      5110        4.11
   7      5654         1766       154      4119      3472        4.11
   8      5654         1788       182      3715      3903        4.11
   9      5654         2130       372      2774      5383        4.11
  10      5654         1897       606      2146      5993        4.11
  11      5654         1392       967      1376      6667        4.11
  12      5654         1047      1516       946      7266        4.12
YEAR 10
   1      5621          937      1353       861      7081        4.12
   2      5621          909       919      1062      6484        4.11
   3      5621         1595       511      2144      5552        4.11
   4      5621         2293       399      2865      5483        4.11
   5      5621         2983       433      3062      5961        4.11
   6      5621         2654       307      3554      5078        4.11
   7      5621         1765       154      4119      3439        4.11
   8      5621         1788       182      3715      3870        4.11
   9      5621         2130       372      2774      5351        4.11
  10      5621         1896       606      2146      5960        4.11
  11      5621         1392       967      1376      6634        4.11
  12      5621         1047      1516       946      7234        4.12
YEAR 11
   1      5587          937      1353       861      7046        4.12
   2      5587          909       919      1062      6450        4.11
   3      5587         1595       511      2143      5518        4.11
   4      5587         2293       399      2865      5449        4.11
   5      5587         2983       433      3062      5926        4.11
   6      5587         2654       307      3554      5044        4.11
   7      5587         1765       154      4118      3405        4.11
   8      5587         1787       182      3715      3836        4.11
   9      5587         2130       372      2773      5316        4.11
  10      5587         1896       606      2146      5926        4.11
  11      5587         1392       967      1376      6600        4.11
  12      5587         1047      1517       946      7199        4.11
YEAR 12
   1      5552          937      1354       861      7010        4.12
   2      5552          909       919      1062      6414        4.11
   3      5552         1595       511      2143      5482        4.11
   4      5552         2293       399      2865      5413        4.11
   5      5552         2983       433      3062      5890        4.11
   6      5552         2654       307      3554      5008        4.11
   7      5552         1765       154      4118      3370        4.11
   8      5552         1787       182      3715      3800        4.11
   9      5552         2130       372      2773      5281        4.11
  10      5552         1896       606      2146      5890        4.11
  11      5552         1392       967      1376      6564        4.11
  12      5552         1047      1517       945      7163        4.11
YEAR 13
   1      5515          937      1354       861      6973        4.12
   2      5515          909       919      1062      6377        4.11
   3      5515         1595       511      2143      5446        4.11
   4      5515         2293       399      2865      5376        4.11
   5      5515         2983       433      3061      5854        4.11
   6      5515         2654       307      3554      4971        4.11
   7      5515         1765       154      4118      3333        4.11
   8      5515         1787       182      3715      3764        4.11
   9      5515         2130       372      2773      5244        4.11
  10      5515         1896       606      2146      5853        4.11
  11      5515         1392       967      1376      6527        4.11
  12      5515         1047      1517       945      7126        4.11
YEAR 14
   1      5477          937      1354       861      6936        4.12
   2      5477          909       919      1062      6339        4.11
   3      5477         1595       511      2143      5408        4.11
   4      5477         2293       399      2865      5338        4.11
   5      5477         2983       433      3061      5816        4.11
   6      5477         2654       307      3554      4933        4.11
   7      5477         1765       154      4118      3296        4.11
   8      5477         1787       182      3714      3726        4.11
   9      5477         2130       372      2773      5206        4.11
  10      5477         1896       606      2145      5815        4.11
  11      5477         1392       967      1376      6489        4.11
  12      5477         1047      1517       945      7088        4.11
YEAR 15
   1      5439          937      1354       861      6897        4.12
   2      5439          909       919      1062      6300        4.11
   3      5439         1595       511      2143      5369        4.11
   4      5439         2293       399      2865      5300        4.11
   5      5439         2982       433      3061      5777        4.11
   6      5439         2653       307      3554      4895        4.11
   7      5439         1765       154      4118      3258        4.11
   8      5439         1787       182      3714      3688        4.11
   9      5439         2130       372      2773      5167        4.11
  10      5439         1896       606      2145      5776        4.11
  11      5439         1392       967      1376      6451        4.11
  12      5439         1047      1517       945      7050        4.11
YEAR 16
   1      5400          937      1354       861      6858        4.12
   2      5400          909       920      1062      6261        4.11
   3      5400         1595       511      2143      5330        4.11
   4      5400         2293       399      2864      5261        4.11
   5      5400         2982       433      3061      5738        4.11
   6      5400         2653       307      3554      4856        4.11
   7      5400         1765       154      4118      3219        4.11
   8      5400         1787       182      3714      3649        4.11
   9      5400         2130       372      2773      5128        4.11
  10      5400         1896       606      2145      5737        4.11
  11      5400         1392       967      1376      6411        4.11
  12      5400         1047      1517       945      7011        4.11
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YEAR 17
   1      5361       937     1354      861     6818      4.12
   2      5361       909      920     1062     6222      4.11
   3      5361      1595      511     2143     5291      4.11
   4      5361      2292      399     2864     5222      4.11
   5      5361      2982      433     3061     5699      4.11
   6      5361      2653      307     3553     4817      4.11
   7      5361      1765      154     4117     3180      4.11
   8      5361      1787      182     3714     3610      4.11
   9      5361      2130      372     2773     5089      4.11
  10      5361      1896      606     2145     5698      4.11
  11      5361      1392      967     1375     6372      4.11
  12      5361      1047     1517      945     6971      4.11
YEAR 18
   1      5322       937     1354      861     6779      4.12
   2      5322       909      920     1062     6183      4.11
   3      5322      1595      511     2143     5252      4.11
   4      5322      2292      399     2864     5182      4.11
   5      5322      2982      433     3061     5659      4.11
   6      5322      2653      307     3553     4778      4.11
   7      5322      1765      154     4117     3141      4.11
   8      5322      1787      182     3714     3571      4.11
   9      5322      2130      372     2773     5050      4.11
  10      5322      1896      606     2145     5659      4.11
  11      5322      1392      968     1375     6333      4.11
  12      5322      1047     1517      945     6932      4.11
YEAR 19
   1      5283       937     1354      861     6740      4.12
   2      5283       909      920     1062     6144      4.11
   3      5283      1595      511     2143     5213      4.11
   4      5283      2292      399     2864     5143      4.11
   5      5283      2982      433     3061     5620      4.11
   6      5283      2653      307     3553     4739      4.11
   7      5283      1765      154     4117     3102      4.11
   8      5283      1787      182     3714     3532      4.11
   9      5283      2129      372     2772     5010      4.11
  10      5283      1896      606     2145     5620      4.11
  11      5283      1392      968     1375     6293      4.11
  12      5283      1047     1517      945     6892      4.11
YEAR 20
   1      5245       937     1354      861     6701      4.12
   2      5245       909      920     1061     6105      4.11
   3      5245      1595      511     2143     5174      4.11
   4      5245      2292      399     2864     5104      4.11
   5      5245      2982      433     3060     5581      4.11
   6      5245      2653      307     3553     4700      4.11
   7      5245      1765      154     4117     3063      4.11
   8      5245      1787      182     3713     3493      4.11
   9      5245      2129      372     2772     4972      4.11
  10      5245      1896      606     2145     5581      4.11
  11      5245      1392      968     1375     6254      4.11
  12      5245      1047     1517      945     6853      4.11
YEAR 21
   1      5206       937     1354      861     6662      4.12
   2      5206       909      920     1061     6066      4.11
   3      5206      1595      511     2143     5135      4.11
   4      5206      2292      399     2864     5066      4.11
   5      5206      2982      433     3060     5543      4.11
   6      5206      2653      307     3553     4661      4.11
   7      5206      1765      154     4117     3025      4.11
   8      5206      1787      182     3713     3455      4.11
   9      5206      2129      372     2772     4933      4.11
  10      5206      1896      606     2145     5542      4.11
  11      5206      1392      968     1375     6216      4.11
  12      5206      1047     1517      945     6815      4.11
YEAR 22
   1      5169       937     1354      861     6624      4.12
   2      5169       909      920     1061     6028      4.11
   3      5169      1595      511     2142     5098      4.11
   4      5169      2292      399     2864     5028      4.11
   5      5169      2981      433     3060     5505      4.11
   6      5169      2653      307     3553     4624      4.11
   7      5169      1765      154     4116     2988      4.11
   8      5169      1786      182     3713     3417      4.11
   9      5169      2129      372     2772     4895      4.11
  10      5169      1895      606     2145     5504      4.11
  11      5169      1392      968     1375     6178      4.11
  12      5169      1047     1517      945     6777      4.11
YEAR 23
   1      5132       937     1354      861     6587      4.12
   2      5132       909      920     1061     5991      4.11
   3      5132      1595      511     2142     5061      4.11
   4      5132      2292      399     2863     4991      4.11
   5      5132      2981      433     3060     5468      4.11
   6      5132      2653      307     3552     4587      4.11
   7      5132      1764      154     4116     2951      4.11
   8      5132      1786      182     3713     3380      4.11
   9      5132      2129      372     2772     4858      4.11
  10      5132      1895      606     2145     5467      4.11
  11      5132      1392      968     1375     6141      4.11
  12      5132      1046     1517      945     6740      4.11
YEAR 24
   1      5096       937     1354      861     6551      4.12
   2      5096       909      920     1061     5955      4.11
   3      5096      1594      511     2142     5025      4.11
   4      5096      2292      399     2863     4955      4.11
   5      5096      2981      433     3060     5432      4.11
   6      5096      2652      307     3552     4551      4.11
   7      5096      1764      154     4116     2915      4.11
   8      5096      1786      182     3713     3344      4.11
   9      5096      2129      372     2772     4822      4.11
  10      5096      1895      606     2144     5431      4.11
  11      5096      1392      968     1375     6105      4.11
  12      5096      1046     1517      945     6704      4.11
YEAR 25
   1      5061       937     1354      861     6516      4.12
   2      5061       909      920     1061     5920      4.11
   3      5061      1594      511     2142     4990      4.11
   4      5061      2292      399     2863     4920      4.11
   5      5061      2981      433     3060     5397      4.11
   6      5061      2652      307     3552     4516      4.11
   7      5061      1764      154     4116     2881      4.11
   8      5061      1786      182     3713     3310      4.10
   9      5061      2129      372     2772     4787      4.11
  10      5061      1895      606     2144     5396      4.11
  11      5061      1391      968     1375     6070      4.11
  12      5061      1046     1517      945     6669      4.11
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of the potential for overflow, since the facility would be subjected to excess rainfall, excessively high influent flows, and low seepage rates simultaneously. If during the computation of the stress analysis water balance, the lagoon exceeds 6.5 feet in depth (freeboard is less than six inches) or falls below two feet in depth, the user is given the option of allowing the model to alter the lagoon design to compensate for these inadequacies and a new facility design computed. Following the stress analysis, the user is given the option of requesting a printed copy of the analysis which includes a twenty-five year monthly water balance showing all component gains and losses to the system under stress conditions and the average monthly operating depth under those conditions. The maximum water depth attained, minimum remaining freeboard, and minimum depth reached during the twenty-five year simulation period is also printed out.

When a run is commenced, the model is initialized at a two-foot operating depth which is consistent with the recommended level of initial filling for new facilities. Model time steps for all water balance component calculations is one month with the exception of lnfluent flow which is recomputed on an annual basis. The facility's initial water surface area, depth above grade, and dike runoff contributing area are all computed relative to the two-foot beginning depth and first month water balance gain components subsequently computed and introduced. From the component gain volumetric inputs a new water volume is computed from which evaporative losses are subsequently subtracted. The resulting volume is computed and a new potential water depth calculated from which seepage is subtracted

Figure 4.47 Onsite Residential Lagoon Design Model Stress Analysis Printout With 25 Year Water Balance

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                 ONSITE RESIDENTIAL LAGOON STRESS ANALYSIS

DESIGN SPECIFICATIONS:

           Number of Dwelling Unit Rooms:                    6
           Inside Dike Slope:                            1:3.0
           Lagoon Depth Below Grade:                     4.0 Ft.
           Bottom Design Area:                            36 Sq. Ft.
           Total Facility Depth:                           7 Ft.
           Dike Freeboard:                                 2 Ft.

STRESS CONDITIONS APPLIED:

           Extreme Climatic Conditions:
                 20-year Annual Rainfall (2nd yr.)          Yes
                 20-year Drought (24th yr.)                 Yes

           High Dwelling Unit Population Density:
                 150% of Normal Density (All Yrs.)          Yes

           Low Facility Seepage Rate:
                 Lower 95% Confidence Band (All Yrs.)       Yes

STRESS ANALYSIS RESULTS:

           Maximum Depth Attained:                         4.47
           Minimum Remaining Freeboard:                    2.53
           Minimum Depth Attained:                         4.40




***************** 25 YEAR WATER BALANCE UNDER STRESS CONDITIONS *****************

 MONTH    INFLUENT     PRECIP.     RUNOFF      EVAP.     SEEPAGE     DEPTH
  no.      gal/mo      gal/mo      gal/mo     gal/mo     gal/mo       ft.

                                  YEAR  1
   1        7367         322        1969        296          0       3.04
   2        7367         897         928       1048       5878       4.24
   3        7367        1778         470       2389       6887       4.41
   4        7367        2591         363       3237       7154       4.43
   5        7367        3364         395       3453       7556       4.43
   6        7367        3005         279       4024       6771       4.43
   7        7367        1989         140       4641       4882       4.42
   8        7367        2012         166       4182       5338       4.42
   9        7367        2400         339       3125       6967       4.42
  10        7367        2138         553       2419       7511       4.43
  11        7367        1576         879       1557       8294       4.44
  12        7367        1184        1379       1070       8741       4.45
                                  YEAR  2
   1        7358        1721        1982        898      10060       4.46
   2        7358        1678        1340       1114       9547       4.45
   3        7358        2918         751       2228       8627       4.44
   4        7358        4215         583       2992       9204       4.45
   5        7358        5482         634       3197      10121       4.46
   6        7358        4906         447       3733       9139       4.46
   7        7358        3245         225       4301       6625       4.44
   8        7358        3270         268       3862       7008       4.43
   9        7358        3900         546       2885       8868       4.44
  10        7358        3481         888       2238       9366       4.45
  11        7358        2566        1412       1441       9933       4.46
  12        7358        1928        2216        989      10394       4.46
                                  YEAR  3
   1        7342        1072        1219        985       8775       4.46
   2        7342        1033         833       1206       8291       4.44
   3        7342        1795         467       2412       7028       4.43
   4        7342        2592         363       3239       7139       4.43
   5        7342        3364         395       3453       7531       4.43
   6        7342        3004         279       4024       6746       4.43
   7        7342        1989         140       4640       4857       4.42
   8        7342        2012         166       4182       5313       4.42
   9        7342        2400         339       3124       6943       4.42
  10        7342        2137         553       2418       7486       4.43
  11        7342        1576         879       1557       8269       4.44
  12        7342        1184        1379       1070       8716       4.45
                                  YEAR  4
   1        7319        1064        1226        978       8638       4.45
   2        7319        1032         833       1206       8262       4.43
   3        7319        1795         467       2412       7005       4.43
   4        7319        2592         363       3239       7117       4.43
   5        7319        3364         395       3453       7509       4.43
   6        7319        3004         279       4023       6724       4.43
   7        7319        1989         140       4640       4834       4.42
   8        7319        2012         166       4182       5290       4.42
   9        7319        2400         339       3124       6921       4.42
  10        7319        2137         553       2418       7464       4.43
  11        7319        1576         879       1557       8247       4.44
  12        7319        1184        1379       1069       8694       4.45
                                  YEAR  5
   1        7291        1064        1227        978       8611       4.45
   2        7291        1032         833       1205       8234       4.43
   3        7291        1795         467       2412       6977       4.43
   4        7291        2592         363       3238       7089       4.43
   5        7291        3363         395       3452       7481       4.43
   6        7291        3004         279       4023       6696       4.43
   7        7291        1989         140       4639       4806       4.42
   8        7291        2012         166       4181       5262       4.42
   9        7291        2399         339       3124       6893       4.42
  10        7291        2137         553       2418       7436       4.43
  11        7291        1576         879       1557       8219       4.44
  12        7291        1184        1379       1069       8666       4.44
                                  YEAR  6
   1        7258        1064        1227        978       8578       4.45
   2        7258        1032         833       1205       8201       4.43
   3        7258        1795         467       2411       6943       4.43
   4        7258        2592         363       3238       7056       4.43
   5        7258        3363         395       3452       7447       4.43
   6        7258        3003         279       4022       6663       4.43
   7        7258        1988         141       4639       4773       4.42
   8        7258        2012         166       4181       5229       4.42
   9        7258        2399         339       3124       6860       4.42
  10        7258        2137         553       2418       7403       4.43
  11        7258        1575         879       1557       8186       4.44
  12        7258        1184        1380       1069       8633       4.44
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                          YEAR  7
  1      7220      1064      1227       978      8540     4.45
  2      7220      1032       833      1205      8163     4.43
  3      7220      1794       467      2411      6905     4.43
  4      7220      2591       363      3238      7018     4.43
  5      7220      3362       395      3451      7410     4.43
  6      7220      3003       279      4022      6625     4.43
  7      7220      1988       141      4638      4734     4.42
  8      7220      2011       166      4181      5192     4.42
  9      7220      2399       339      3123      6823     4.42
 10      7220      2136       553      2417      7365     4.43
 11      7220      1575       880      1557      8148     4.44
 12      7220      1184      1380      1069      8595     4.44
                          YEAR  8
  1      7178      1064      1227       977      8499     4.45
  2      7178      1032       834      1205      8122     4.43
  3      7178      1794       467      2410      6863     4.42
  4      7178      2591       363      3237      6976     4.43
  5      7178      3362       395      3451      7368     4.43
  6      7178      3003       279      4021      6583     4.43
  7      7178      1988       141      4637      4692     4.42
  8      7178      2011       166      4180      5150     4.42
  9      7178      2399       339      3123      6781     4.42
 10      7178      2136       553      2417      7323     4.43
 11      7178      1575       880      1556      8107     4.44
 12      7178      1184      1380      1069      8553     4.44
                          YEAR  9
  1      7133      1064      1227       977      8454     4.45
  2      7133      1032       834      1205      8077     4.43
  3      7133      1794       467      2410      6817     4.42
  4      7133      2590       363      3237      6931     4.43
  5      7133      3361       395      3450      7322     4.43
  6      7133      3002       279      4021      6538     4.43
  7      7133      1988       141      4637      4647     4.42
  8      7133      2011       166      4180      5105     4.42
  9      7133      2398       339      3123      6737     4.42
 10      7133      2136       553      2417      7278     4.43
 11      7133      1575       880      1556      8061     4.44
 12      7133      1183      1380      1069      8508     4.44
                          YEAR 10
  1      7084      1064      1227       977      8406     4.45
  2      7084      1032       834      1205      8029     4.43
  3      7084      1793       467      2409      6768     4.42
  4      7084      2590       363      3236      6883     4.43
  5      7084      3361       395      3450      7274     4.43
  6      7084      3002       279      4020      6489     4.43
  7      7084      1987       141      4636      4598     4.42
  8      7084      2011       166      4179      5057     4.42
  9      7084      2398       339      3122      6689     4.42
 10      7084      2135       553      2416      7230     4.43
 11      7084      1574       880      1556      8013     4.44
 12      7084      1183      1380      1068      8460     4.44
                          YEAR 11
  1      7033      1063      1228       977      8355     4.45
  2      7033      1031       834      1204      7978     4.43
  3      7033      1793       467      2409      6717     4.42
  4      7033      2589       363      3235      6832     4.43
  5      7033      3360       395      3449      7223     4.43
  6      7033      3001       280      4019      6439     4.43
  7      7033      1987       141      4635      4547     4.42
  8      7033      2010       166      4178      5007     4.42
  9      7033      2398       339      3122      6639     4.42
 10      7033      2135       553      2416      7179     4.43
 11      7033      1574       880      1556      7963     4.44
 12      7033      1183      1381      1068      8409     4.44
                          YEAR 12
  1      6980      1063      1228       977      8302     4.45
  2      6980      1031       834      1204      7926     4.43
  3      6980      1793       467      2408      6663     4.42
  4      6980      2589       363      3235      6779     4.43
  5      6980      3360       395      3448      7170     4.43
  6      6980      3000       280      4018      6385     4.43
  7      6980      1986       141      4634      4493     4.42
  8      6980      2010       166      4178      4954     4.42
  9      6980      2397       340      3121      6586     4.42
 10      6980      2135       553      2415      7126     4.43
 11      6980      1574       880      1555      7910     4.44
 12      6980      1183      1381      1068      8356     4.44
                          YEAR 13
  1      6925      1063      1228       976      8247     4.45
  2      6925      1031       834      1204      7871     4.43
  3      6925      1792       467      2408      6607     4.42
  4      6925      2589       363      3234      6725     4.43
  5      6925      3359       395      3448      7115     4.43
  6      6925      3000       280      4018      6331     4.43
  7      6925      1986       141      4633      4438     4.42
  8      6925      2010       166      4177      4899     4.42
  9      6925      2397       340      3121      6532     4.42
 10      6925      2134       553      2415      7071     4.43
 11      6925      1574       880      1555      7855     4.43
 12      6925      1182      1381      1068      8301     4.44
                          YEAR 14
  1      6868      1063      1228       976      8191     4.45
  2      6868      1031       834      1204      7815     4.43
  3      6868      1792       467      2407      6550     4.42
  4      6868      2588       363      3234      6668     4.43
  5      6868      3358       395      3447      7059     4.43
  6      6868      2999       280      4017      6274     4.43
  7      6868      1986       141      4632      4381     4.42
  8      6868      2010       166      4177      4844     4.42
  9      6868      2397       340      3120      6477     4.42
 10      6868      2134       554      2414      7015     4.43
 11      6868      1573       880      1555      7799     4.43
 12      6868      1182      1381      1068      8245     4.44
                          YEAR 15
  1      6811      1062      1228       976      8134     4.45
  2      6811      1030       835      1203      7758     4.43
  3      6811      1791       467      2407      6492     4.42
  4      6811      2588       363      3233      6611     4.43
  5      6811      3358       396      3446      7001     4.43
  6      6811      2999       280      4016      6217     4.43
  7      6811      1985       141      4632      4323     4.42
  8      6811      2009       167      4176      4787     4.42
  9      6811      2396       340      3120      6420     4.42
 10      6811      2133       554      2414      6957     4.43
 11      6811      1573       881      1554      7742     4.43
 12      6811      1182      1382      1067      8187     4.44
                          YEAR 16
  1      6753      1062      1229       976      8076     4.45
  2      6753      1030       835      1203      7701     4.43
  3      6753      1791       468      2406      6434     4.42
  4      6753      2587       363      3232      6553     4.43
  5      6753      3357       396      3446      6943     4.43
  6      6753      2998       280      4015      6159     4.43
  7      6753      1985       141      4631      4264     4.41
  8      6753      2009       167      4175      4729     4.41
  9      6753      2396       340      3119      6363     4.42
 10      6753      2133       554      2413      6899     4.43
 11      6753      1573       881      1554      7685     4.43
 12      6753      1182      1382      1067      8129     4.44
```

```
                              YEAR 17
 1      6694      1062      1229       976      8018      4.45
 2      6694      1030       835      1203      7643      4.43
 3      6694      1790       468      2406      6375      4.42
 4      6694      2587       363      3232      6495      4.42
 5      6694      3356       396      3445      6885      4.43
 6      6694      2997       280      4014      6100      4.43
 7      6694      1985       141      4630      4205      4.41
 8      6694      2009       167      4175      4671      4.41
 9      6694      2396       340      3119      6305      4.42
10      6694      2133       554      2413      6841      4.43
11      6694      1572       881      1554      7627      4.43
12      6694      1181      1382      1067      8071      4.44
                              YEAR 18
 1      6636      1062      1229       975      7959      4.45
 2      6636      1030       835      1202      7585      4.43
 3      6636      1790       468      2405      6315      4.42
 4      6636      2586       363      3231      6437      4.42
 5      6636      3355       396      3444      6826      4.43
 6      6636      2997       280      4013      6042      4.42
 7      6636      1984       141      4629      4146      4.41
 8      6636      2008       167      4174      4613      4.41
 9      6636      2395       340      3118      6248      4.42
10      6636      2132       554      2413      6783      4.43
11      6636      1572       881      1553      7569      4.43
12      6636      1181      1382      1067      8013      4.44
                              YEAR 19
 1      6577      1062      1229       975      7901      4.45
 2      6577      1030       835      1202      7527      4.43
 3      6577      1790       468      2404      6256      4.42
 4      6577      2586       363      3230      6379      4.42
 5      6577      3355       396      3443      6748      4.43
 6      6577      2996       280      4013      5984      4.42
 7      6577      1984       141      4628      4087      4.41
 8      6577      2008       167      4174      4555      4.41
 9      6577      2395       340      3118      6190      4.42
10      6577      2132       554      2412      6724      4.42
11      6577      1572       881      1553      7511      4.43
12      6577      1181      1383      1066      7954      4.44
                              YEAR 20
 1      6519      1061      1230       975      7843      4.44
 2      6519      1029       835      1202      7469      4.43
 3      6519      1789       468      2404      6198      4.42
 4      6519      2585       364      3230      6321      4.42
 5      6519      3354       396      3443      6710      4.43
 6      6519      2996       280      4012      5926      4.42
 7      6519      1983       141      4627      4029      4.41
 8      6519      2008       167      4173      4497      4.41
 9      6519      2394       340      3117      6133      4.42
10      6519      2131       554      2412      6667      4.42
11      6519      1571       881      1553      7453      4.43
12      6519      1181      1383      1066      7897      4.44
                              YEAR 21
 1      6462      1061      1230       975      7786      4.44
 2      6462      1029       836      1202      7413      4.43
 3      6462      1789       468      2403      6140      4.42
 4      6462      2585       364      3229      6264      4.42
 5      6462      3353       396      3442      6653      4.42
 6      6462      2995       280      4011      5869      4.42
 7      6462      1983       141      4626      3971      4.41
 8      6462      2008       167      4173      4441      4.41
 9      6462      2394       340      3117      6077      4.42
10      6462      2131       554      2411      6610      4.42
11      6462      1571       882      1552      7396      4.43
12      6462      1180      1383      1066      7839      4.44
                              YEAR 22
 1      6406      1061      1230       975      7730      4.44
 2      6406      1029       836      1201      7357      4.42
 3      6406      1788       468      2403      6083      4.42
 4      6406      2584       364      3229      6208      4.42
 5      6406      3353       396      3441      6596      4.42
 6      6406      2994       280      4010      5812      4.42
 7      6406      1983       141      4625      3915      4.41
 8      6406      2007       167      4172      4385      4.41
 9      6406      2394       340      3116      6021      4.41
10      6406      2131       554      2411      6554      4.42
11      6406      1571       882      1552      7341      4.43
12      6406      1180      1383      1066      7783      4.44
                              YEAR 23
 1      6350      1061      1230       974      7675      4.44
 2      6350      1029       836      1201      7302      4.42
 3      6350      1788       468      2402      6027      4.42
 4      6350      2584       364      3228      6153      4.42
 5      6350      3352       396      3441      6541      4.42
 6      6350      2994       280      4010      5757      4.42
 7      6350      1982       141      4625      3859      4.41
 8      6350      2007       167      4171      4330      4.41
 9      6350      2393       340      3116      5967      4.41
10      6350      2130       554      2410      6499      4.42
11      6350      1570       882      1552      7286      4.43
12      6350      1180      1384      1065      7728      4.44
                              YEAR 24
 1      6297       712       826      1034      6861      4.44
 2      6297       688       562      1271      6564      4.42
 3      6297      1197       315      2542      5089      4.41
 4      6297      1729       245      3416      4956      4.41
 5      6297      2242       267      3638      5067      4.41
 6      6297      2000       189      4236      4382      4.41
 7      6297      1325        95      4888      2802      4.40
 8      6297      1344       112      4417      3316      4.41
 9      6297      1603       229      3299      4850      4.41
10      6297      1425       373      2549      5419      4.41
11      6297      1051       594      1641      6334      4.42
12      6297       789       931      1127      6771      4.43
                              YEAR 25
 1      6245      1057      1234       971      7513      4.44
 2      6245      1028       836      1200      7194      4.42
 3      6245      1787       468      2401      5920      4.42
 4      6245      2583       364      3227      6048      4.42
 5      6245      3351       396      3440      6436      4.42
 6      6245      2993       280      4008      5652      4.42
 7      6245      1782       141      4623      3752      4.41
 8      6245      2007       167      4170      4225      4.41
 9      6245      2393       340      3115      5863      4.41
10      6245      2129       555      2409      6393      4.42
11      6245      1570       882      1551      7181      4.43
12      6245      1179      1384      1065      7623      4.43
```

based upon the new depth above the surrounding grade. The resulting final water balance for the end of the initial month of operation is added to the initial depth and divided by two to determine the average operating depth for the facility for the initial month of operation.

The water depth at the end of the initial month provides the basis for determining the initial water surface area, initial dike runoff area and initial volume for the second month of operation. Second month gain calculations can then be made, followed by subsequent computation of evaporative losses, a new potential operating depth and, finally, seepage losses. This iterative process is repeated throughout the twenty-five year design life of the facility, or until design bottom area changes are necessitated to achieve the optimum five-foot operating depth. If the five-foot normal optimum operating depth is not achieved within the first three years of operation, the facility design is altered and the water balance computations reinitialized automatically until the optimum depth is achieved or the default design minimum level is reached.

## Influent Flows

Estimated influent flows during the twenty-five year design life of the model-designed facilities are based upon the results of the demographic changes analysis of Tulsa 1960, 1970 and 1980 census data (see Chapters III and IV). The decline in dwelling unit population as the age of the unit increases, which has been previously documented, reflects changes occurring during the twenty year period 1960 through 1980 but, unfortunately, also reflects the decrease in family size which has occurred during that twenty year period as a result of declining birth rates in the United States and in the Tulsa area. It was necessary, therefore, to adjust the rate of decline in dwelling unit population to reflect more current housing unit population density levels.

Figure 4.48 shows the relationship between the population per room of owner-occupied dwelling units and median dwelling unit age. The resulting regression line predicts a density decline of from approximately .8 persons per room when the dwelling unit is new to approximately .4 persons per room when the unit reaches forty years of age. However, the population density of the new dwelling unit reflects conditions which prevailed in the early 1960's rather than those existing today. Consequently, it was necessary to adjust the initial population per room dwelling unit density downward to reflect current density levels. This subsequently required adjustment of the entire regression line. Census data for selected 1980 Tulsa County census tracts which exhibited low dwelling unit median ages (between two and eight years) and small percentages of renter-occupied units, indicate today's dwelling unit population density is approximately .54 persons per room on the average. Average median age of the selected tracts was 5.1 years. This more current density figure was employed as the basis for adjusting the regression line model. The line was adjusted downward to reflect a population per room density of .54 at 5.1 years of dwelling unit age but retained the same population density at forty-five years of age (current day population density conditions). The line was incrementally adjusted by an inverse

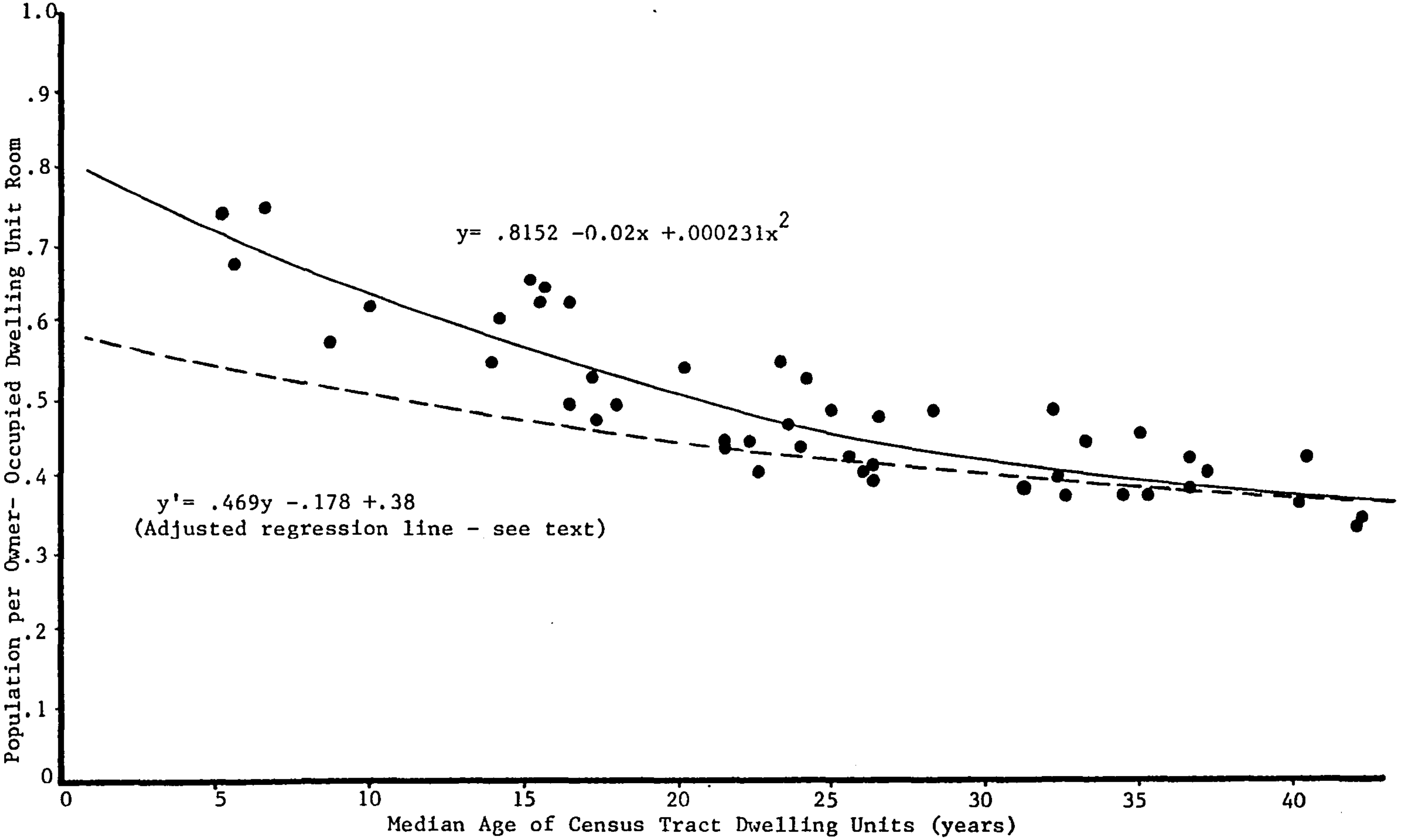


Figure 4.48 Adjusted Regression Model for Predicting Population per Room of Owner-Occupied Dwelling Units from Median Dwelling Unit Age

proportionality technique throughout the entire forty-year dwelling unit age span. This adjustment, and the associated adjusted (dashed) regression line are also shown in Figure 4.48.

By employing the adjusted regression line equation, the model computes the population density of the household on an annual basis througout the twenty-five year design life of the model as the dwelling unit is incrementally aged on an annual basis.

From these population per room density estimates the total estimated number of occupants of the dwelling unit to be served by the facility is computed, based upon the specified number of rooms. As was discussed in previous sections of this chapter, the best multiple regression relationships for estimating wastewater flows from demographic variables were based upon numbers of dwelling unit occupants and the ages of those occupants. A multiple regression relationship was developed for estimating dwelling unit water consumption on the basis of three age categories including: Children newborn through nine years; children ages nine through twenty years, and adults greater than twenty years. The percentages of dwelling unit occupants falling into these three age categories in the selected Tulsa census tracts was determined and their relationship to a median ages of census tract dwelling units was developed. The result was a relatively accurate set of predictive regression equations for each of the three age categories as presented in Figures 4.49, 4.50 and 4.51. The additive percentages of the three age categories during all years of the dwelling unit aging process was very nearly 100 percent, attesting to the accuracy of the methodology (see Table 4.6).

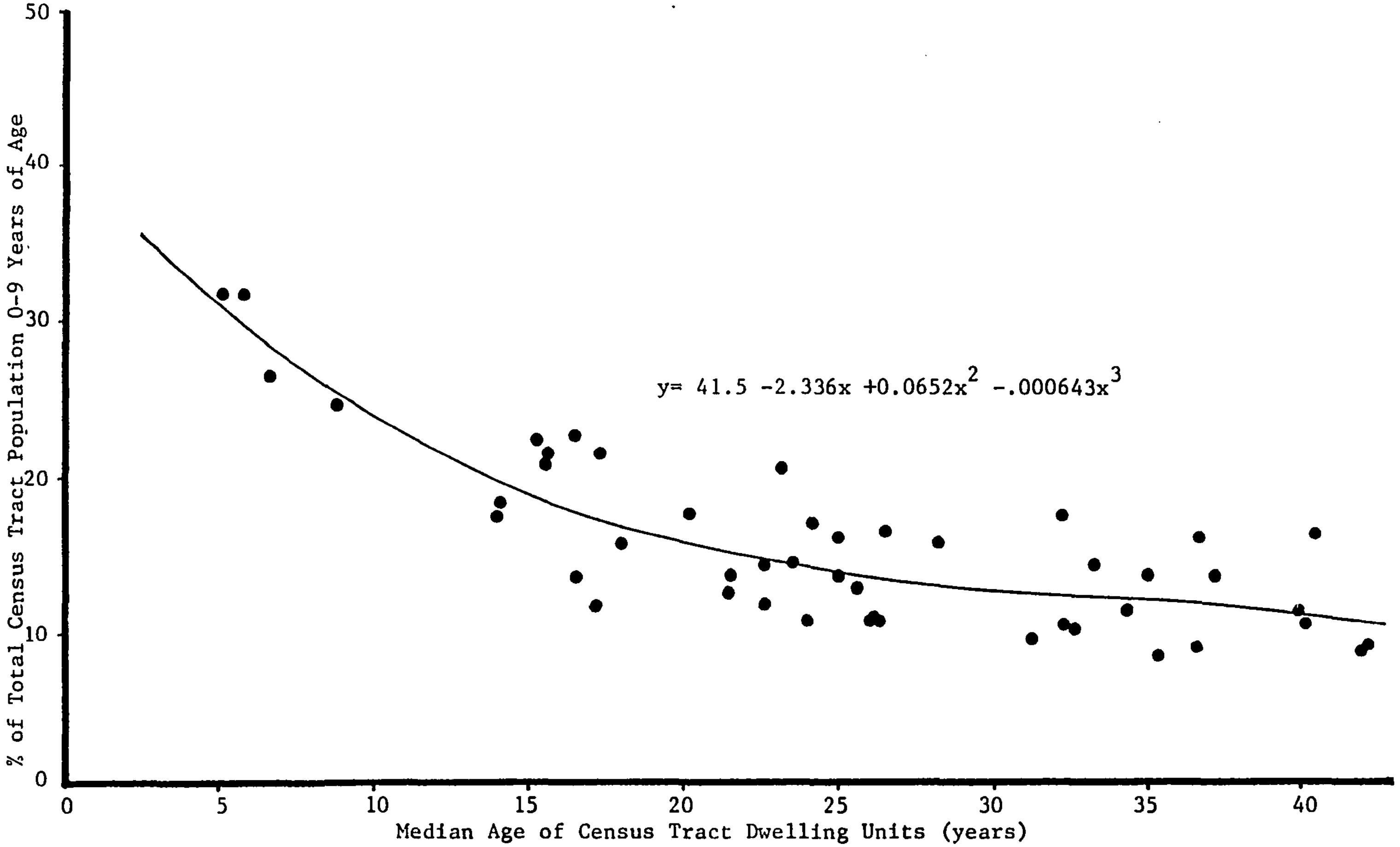


Figure 4.49 Median Age of Census Tract Dwelling Units Versus Percentage of Census Tract Population 0-9 Years of Age in Selected Tulsa, Oklahoma Census Tratcs in 1960, 1970 and 1980

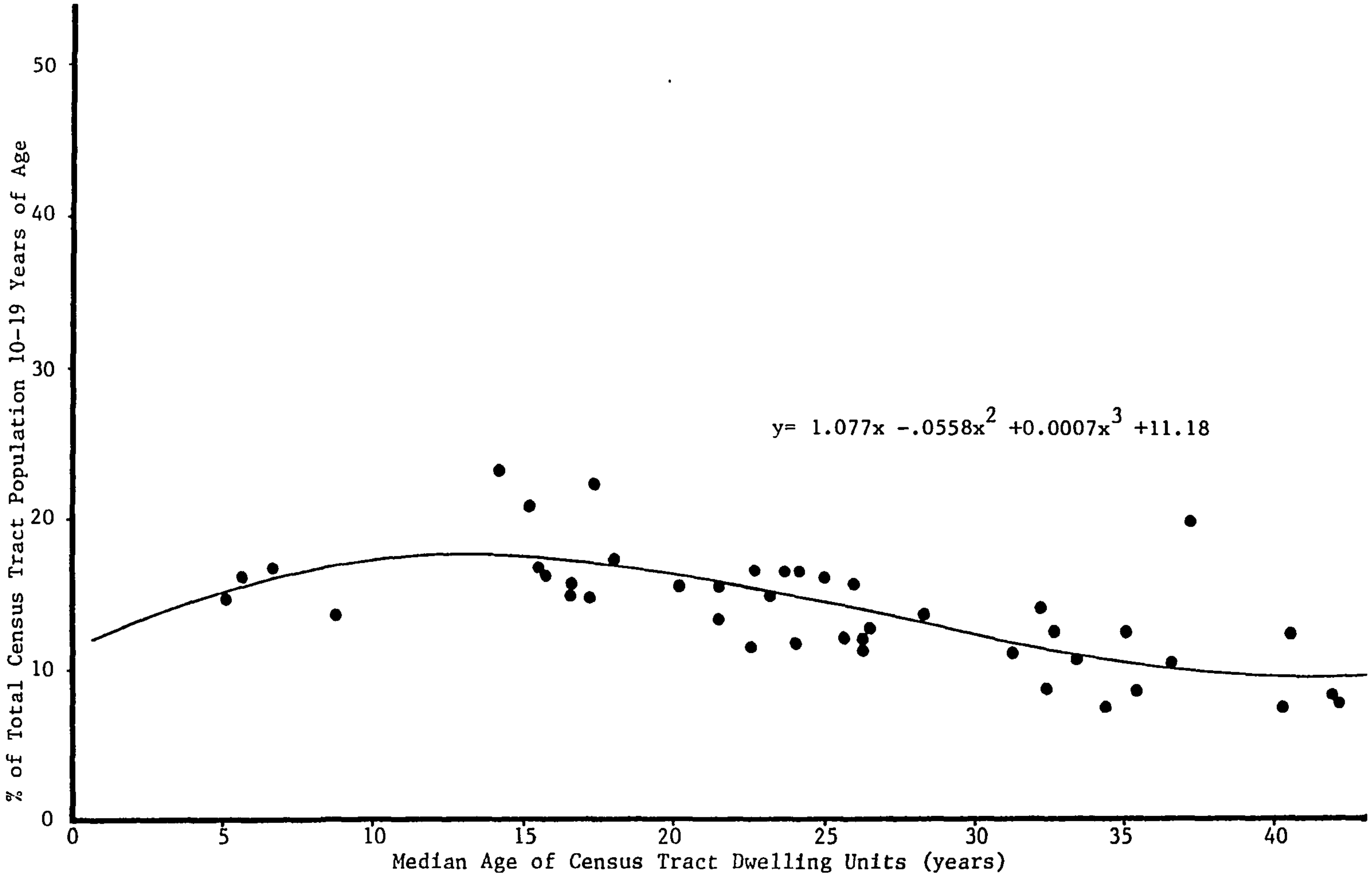


Figure 4.50 Median Age of Census Tract Dwelling Units Versus Percentage of Census Tract Population 10-19 Years of Age in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980

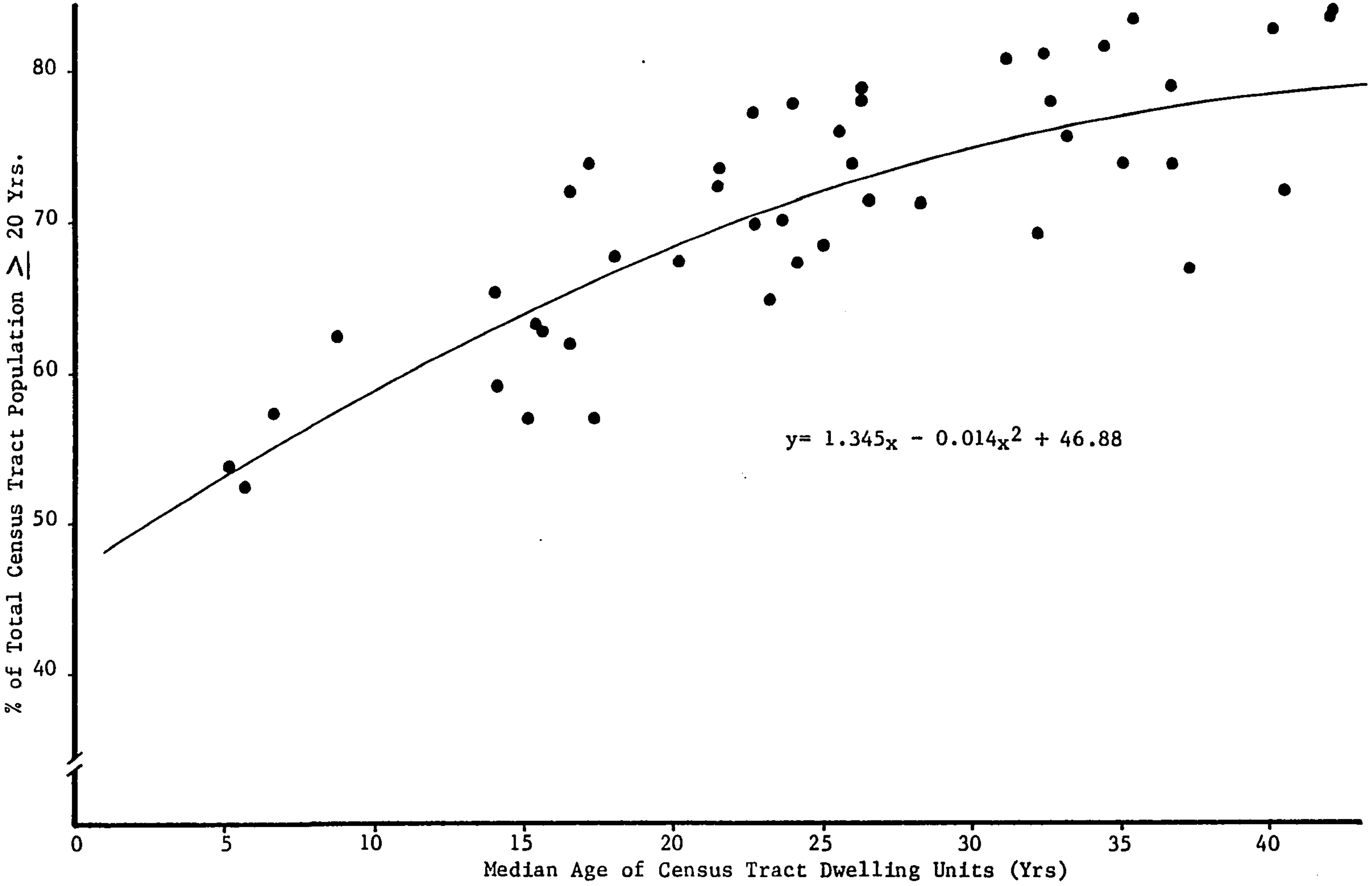


Figure 4.51 Median Age of Census Tract Dwelling Units Versus Percentage of Census Tract Population Equal to or Greater Than 20 Years of Age in Selected Tulsa, Oklahoma Census Tracts in 1960, 1970 and 1980.

## TABLE 4.6

## PERCENTAGE DISTRIBUTION OF DWELLING UNIT OCCUPANTS BY AGE GROUP AND DWELLING UNIT AGE FOR SELECTED TULSA, OKLAHOMA CENSUS TRACTS*

| Dwelling Unit Age (yrs) | Age Group Category (Years) | | | % Total |
|---|---|---|---|---|
| | 0-9 | 10-19 | 20 | |
| 1 | 39.2 | 12.2 | 48.2 | 99.6 |
| 5 | 31.3 | 15.2 | 53.2 | 99.7 |
| 10 | 24.0 | 17.1 | 58.9 | 100.0 |
| 15 | 18.9 | 17.1 | 63.9 | 99.0 |
| 20 | 15.7 | 16.0 | 68.2 | 99.0 |
| 25 | 13.8 | 14.2 | 71.8 | 99.8 |
| 30 | 12.7 | 12.2 | 74.6 | 99.5 |
| 35 | 12.0 | 10.5 | 76.8 | 99.3 |
| 40 | 11.2 | 9.8 | 78.3 | 99.3 |

* Percentages Calculated from regression equations based upon 1960, 1970 and 1980 census data for selected Tulsa, Oklahoma census tracts - see text and Figures 4.49, 4.50 and 4.51.

From these three regression equations (relating percent of population in the three age categories to median age of the dwelling unit) the model calculates the annual average number of dwelling unit occupants to be served by the lagoon in each of the three age categories as the unit ages during its twenty-five year design life. The resulting age-specific dwelling unit population provides the necessary inputs for determining dwelling unit wastewater flow through the multiple regression equation previously discussed. Influent flows thus determined are recomputed on annual time steps during the model iterations.

## Precipitation Gains

Precipitation inputs into the lagoon design modeling process are separated into incident precipitation to the lagoon water surface and precipitation runoff from the interior slopes of the dikes. During the initial design iterations, precipitation inputs to the water surface are based upon median annual precipitation which is 36.5 inches per year for the Tulsa area. This total annual median rainfall is distributed among the twelve months of each year based upon the normal average percent distribution per month. This varies from a low of 4.24 percent in February to 13.95 percent in May. The coefficients for monthly modification of the median annual rainfall figure are contained in the design model data matrix shown in Table 4.7.

During stress analysis simulations of the model run, ninety-five percent and five percent probability level rainfalls are applied during the second and twenty-fourth years, respectively, to simulate

## TABLE 4.7

## ONSITE LAGOON DESIGN MODEL DATA MATRIX[1]

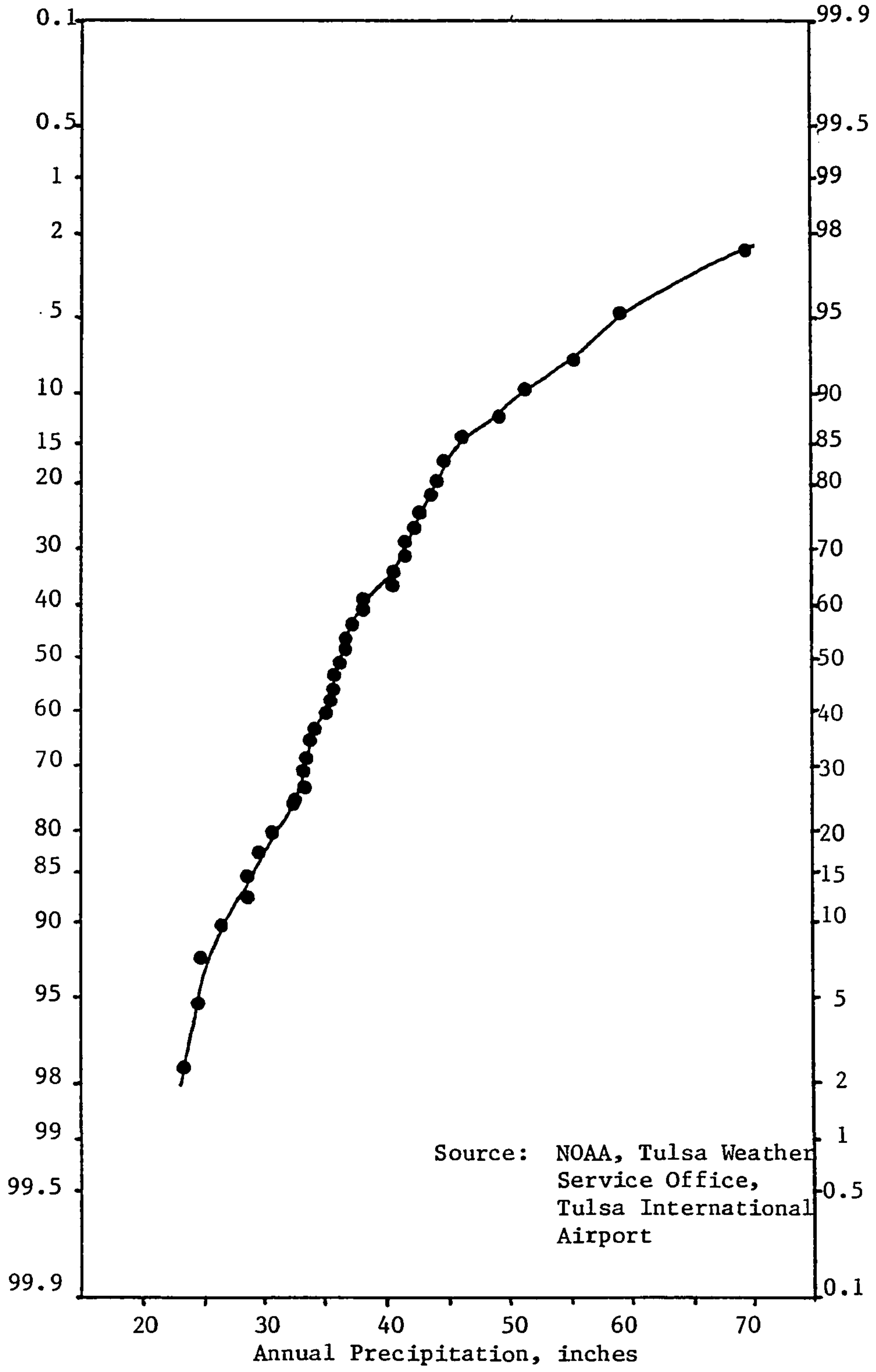
| MONTH NO. | NO. OF DAYS PER MONTH A(K,1) | % OF ANNUAL EVAPORATION A(K,2) | % OF ANNUAL RAINFALL A(K,3) | % DIKE RUNOFF A(K,4) |
|---|---|---|---|---|
| 1 | 31 | .030 | .0437 | 1.00 |
| 2 | 28 | .037 | .0424 | 0.70 |
| 3 | 31 | .075 | .0747 | 0.22 |
| 4 | 30 | .100 | .1071 | 0.12 |
| 5 | 31 | .107 | .1395 | 0.10 |
| 6 | 30 | .124 | .1239 | 0.08 |
| 7 | 31 | .144 | .0826 | 0.06 |
| 8 | 31 | .130 | .0837 | 0.07 |
| 9 | 30 | .097 | .0997 | 0.12 |
| 10 | 31 | .075 | .0887 | 0.22 |
| 11 | 30 | .048 | .0650 | 0.48 |
| 12 | 31 | .033 | .0489 | 1.00 |

[1] Filename: "PPCTEVAP.DA"; 12X4

excess rainfall and drought conditions. These conditions correspond to a twenty-year annual rainfall and a twenty-year drought, respectively and were determined from the probability distribution of annual precipitation for Tulsa, Oklahoma, based upon Tulsa Weather Office records for the period 1943 through 1982 (see figure 4.52).

## Precipitation Runoff

The second precipitation gain component is precipitation runoff from the lagoon dikes. The methodology for determining the percentage of runoff from the dikes as related to average daily pan evaporation, has been discussed in previous sections of Chapter IV. The relationship was summarized in Figure 4.23. The monthly average percentages of precipitation runoff resulting from this relationship, as shown in Table 4.8, are contained in the lagoon design model data matrix where they provide the necessary monthly coefficients for determining the percentage of dike precipitation runoff contributing to the lagoon water volume. Results of the precipitation runoff calculations are introduced into water balance iterations monthly. The median annual inches of precipitation and its monthly distribution is equivalent to that employed for water surface incident precipitation. Stress analysis ninety-five percent and five percent probability level quantities are also the same as those for incident precipitation.



Source: NOAA, Tulsa Weather Service Office, Tulsa International Airport

Figure 4.52 Probability Distribution of Annual Precipitation at Tulsa, Oklahoma, 1943-1982

## TABLE 4.8

## AVERAGE DAILY PAN EVAPORATION AND AVERAGE PERCENTAGE OF LAGOON DIKE RUNOFF BY MONTH FOR THE TULSA, OKLAHOMA METROPOLITAN AREA[1]

| MONTH | AVG. DAILY PAN EVAPORATION | AVG.% RUNOFF[2] |
|---|---|---|
| January | .066 | 100 |
| February | .091 | 70 |
| March | .167 | 22 |
| April | .228 | 12 |
| May | .246 | 10 |
| June | .284 | 8 |
| July | .319 | 6 |
| August | .289 | 7 |
| September | .221 | 12 |
| October | .165 | 22 |
| November | .110 | 48 |
| December | .074 | 100 |

[1] Based upon average monthly evaporation rates/days per month. (Average monthly evaporation rates are period of record average monthly pan evaporation rates of U.S. Corps of Engineers project sites, Heyburn, Oolagah, Keystone, Grand and Ft. Gibson).

[2] From curve presented in Figure 4.23.

## Evaporative Losses

After the input of influent and precipitation gains to the lagoon water volume, the model subtracts evaporative losses based upon the monthly distribution of median annual lake evaporation for the Tulsa area. Median annual pan evaporation was determined to be 68.6 inches. This figure is based upon the average period of record annual evaporative totals for the U.S. Corp of Engineers, Fort Gibson Project Site located east of Tulsa, which is 66.1 inches per year, plus 2.5 inches, the approximate average increase in pan evaporation which occurs in the Tulsa area over that at Fort Gibson, according to U.S. Weather Bureau evaporation studies(14). This median annual pan evaporation figure of 68.6 is very nearly equivalent to the mean pan evaporation for all of the Corp project sites included in Table 4.9. The median annual figure is adjusted to simulate lake evaporation by utilizing a lake evaporation coefficient of .712 (14). The resulting median annual lake evaporation is divided into monthly normal lake evaporation on the basis of the percentage of evaporation occurring during each month of the year (based upon the Corp project site monthly data in Figure 4.9).

Fort Gibson project site median annual pan evaporation was determined from the probability distribution of that data presented in Figure 4.53. During stress analysis simulations, evaporation rates which might be expected to occur during times of above and below normal rainfall are determined from the relationship and associated regression equation presented in Figure 4.54. In that figure, annual

## TABLE 4.9

## AVERAGE MONTHLY PAN EVAPORATION FOR TULSA DISTRICT U.S. CORPS ENGINEERS PROJECT SITES[1]

| Month | Heyburn | Oolagah | Keystone | Grand | Ft.Gibson | Mean | % |
|---|---|---|---|---|---|---|---|
| Jan | 1.93 | 1.86 | 2.30 | 2.15 | 2.02 | 2.05 | 3.0 |
| Feb | 2.67 | 2.61 | 2.40 | 2.46 | 2.54 | 2.54 | 3.7 |
| Mar | 4.77 | 5.40 | 5.10 | 6.02 | 4.61 | 5.18 | 7.5 |
| Apr | 6.70 | 7.26 | 6.77 | 7.18 | 6.34 | 6.85 | 10.0 |
| May | 7.06 | 8.16 | 7.01 | 7.46 | 7.18 | 7.37 | 10.7 |
| Jun | 8.12 | 9.03 | 8.15 | 8.88 | 8.48 | 8.53 | 12.4 |
| Jul | 9.56 | 10.85 | 9.85 | 9.88 | 9.28 | 9.88 | 14.4 |
| Aug | 8.59 | 10.04 | 8.94 | 9.45 | 8.81 | 8.97 | 13.0 |
| Sep | 6.24 | 7.23 | 6.21 | 6.93 | 6.58 | 6.64 | 9.7 |
| Oct | 4.69 | 5.64 | 5.05 | 5.24 | 5.02 | 5.13 | 7.5 |
| Nov | 2.99 | 3.25 | 3.13 | 3.97 | 3.16 | 3.30 | 4.8 |
| Dec | 2.13 | 1.92 | 2.03 | 3.27 | 2.11 | 2.29 | 3.3 |
| Total | 65.45 | 73.25 | 66.94 | 72.89 | 66.13 | 68.73 | 100.0 |

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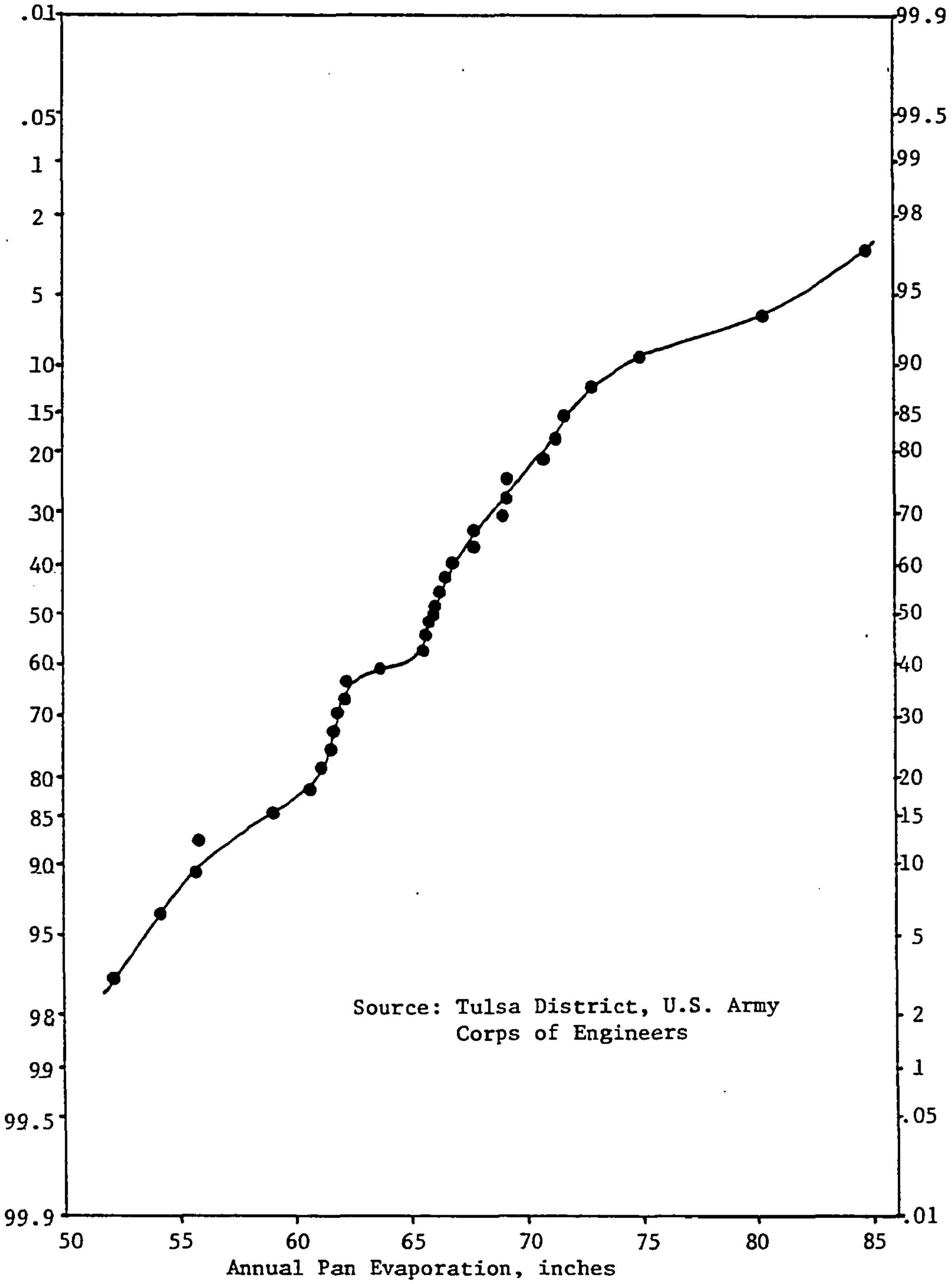
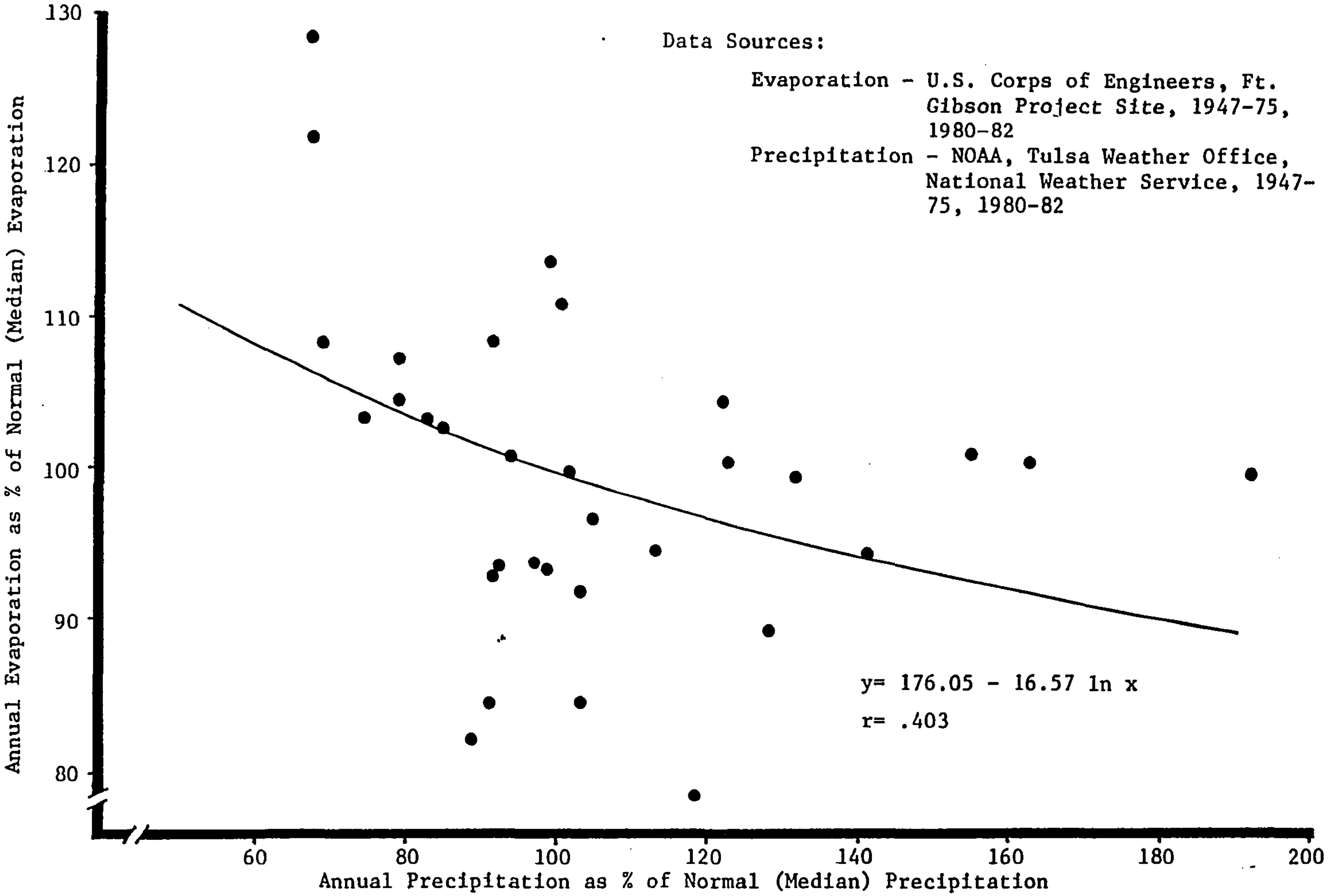
[1] Source: Tulsa Disctrict, U.S. Corps of Engineers(15).



Source: Tulsa District, U.S. Army Corps of Engineers

Figure 4.53 Probability Distribution of Annual Class A Pan Evaporation at Lake Ft. Gibson Project Site, 1947-1975, 1980-1982



Data Sources:

Evaporation - U.S. Corps of Engineers, Ft. Gibson Project Site, 1947-75, 1980-82

Precipitation - NOAA, Tulsa Weather Office, National Weather Service, 1947-75, 1980-82

$y= 176.05 - 16.57 \ln x$

$r= .403$

Figure 4.54 Tulsa Annual Precipitation as Percentage of Normal Versus Ft. Gibson Project Site Annual Evaporation as Percentage of Normal, 1947-75, 1980-82 evaporation, as a percentage of normal evaporation, is related to annual precipitation as a percentage of normal precipitation. Although the relationship is marked by significant variance (r =.403), the tendency toward increased evaporation, on an annual basis, during times of below normal precipitation, and vice versa, is apparent. The equation defining this relationship is employed in the model as the means of estimating evaporation rates during stress analysis simulations corresponding to the ninety-five percent and five percent rainfall probability levels in lieu of utilizing evaporation probability levels based upon evaporation return period frequencies.

The coefficients for monthly distribution of annual median evaporation are contained in the design model data matrix (Table 4.7) and are introduced into the water balance computations on a monthly basis.

### Seepage Losses

The methodology employed to determine seepage losses from lagoons has been extensively discussed. The equation for predicting such losses, as employed in the model, is based upon regression analysis of lagoon seepage rates versus potential rises in lagoon level above the surrounding grades as shown in Figure 4.27. The loss is based upon vertical loss in lagoon depth after all other gains and evaporative losses are accounted for, to establish a new lagoon operating level. All other water balance losses and gains are computed on a volumetric basis. During stress analysis, the rate of seepage from the facility is lowered, if the decreased seepage option is chosen, to the lower ninety-five percent confidence band for the relationship depicted in Figure 4.27.

## Comparative Results

It became quickly apparent, during consecutive runs of the lagoon computer design model utilizing different below grade depths and various size dwelling units, that the water balance of these facilities is dominated by the lagoon seepage rate component. It is obvious, by referring to Figure 4.27, that the rate of seepage from these facilities is nearly equivalent to the rise in level above grade, under most conditions, although some of the input volume from influents and precipitation is retained. Dramatic rises in lagoon level in the range of .5 inches per day will be nearly absorbed (seepage loss will be approximately .45 inches per day) by the lagoon dikes in the wetted area above grade. Because of the unusually strong influence of seepage in controlling lagoon water levels, the design model computes the same default level (six by six feet; 36 square feet) bottom design for all dwelling units up to twelve rooms, if a conventional 3.5 or 4-foot below grade depth is used. Even under stress conditions this size of facility accomodates the waste flows without unacceptable fluctuations in depth, i.e., acceptable freeboard is retained. Because of the small water surface area, the facility is not significantly affected by drought conditions.

Table 4.10 compares the results of facilities designed by the computer model with those designed under current Oklahoma State Department of Health design criteria[1] for two-, three-, and four-bedroom dwelling units. Since the model operates on the basis of dwelling unit rooms, rather than bedrooms, it was necessary to calculate equivalent numbers of dwelling unit rooms for corresponding numbers of bedrooms. These calculations were based upon census data regression results as indicated in the footnotes to Table 4.10. By referring to that table, it is apparent that the model-designed facilities are all adequate to assimilate the greater influent flows from the increasingly larger dwelling units by dissipating water via dike seepage while still retaining acceptable maximum and minimum water depths. It is important to note in Table 4.10, that the increase in seepage is roughly equivalent only to the increase in influent flows since this smaller design is subjected to less water gain from direct and dike runoff precipitation inputs. For example, although the overall lagoon area of the state design for a four-bedroom dwelling unit is over twice as large as that of a model-designed four-bedroom house (12,100 square feet as compared with 5,476 square feet), the increase in seepage required to maintain roughly equivalent operating depths between the two facilities is only 1,645 gal/mo. The computer model-designed facility loses 7,166 gal/mo compared with a 5,521 gal/mo seepage loss from the state designed facility. The reason for the comparatively small increase in seepage to maintain equivalent operating depths is the greatly reduced precipitation inputs (about one-fourth as much) into the smaller facility.

The surface $BOD_5$ loading to the computer model-designed lagoons is substantially higher than that for facilities designed under state

## TABLE 4.10

## SPECIFICATIONS AND OPERATIONAL CHARACTERISTICS OF LAGOONS DESIGNED TO SERVE TWO-, THREE-, AND FOUR-BEDROOM DWELLINGS ACCORDING TO OSDH DESIGN CRITERIA AS COMPARED WITH DESIGN MODEL OUTPUT

| | OSDH DESIGN CRITERIA[1] | DESIGN MODEL | OSDH DESIGN CRITERIA[1] | DESIGN MODEL | OSDH DESIGN CRITERIA[1] | DESIGN MODEL |
|---|---|---|---|---|---|---|
| DESIGN SPECIFICATIONS: | | | | | | |
| No. D.U. Rooms[2] | 4.5(equiv) | 4.5 | 6.5(equiv) | 6.5 | 8.5(equiv) | 8.5 |
| No. D.U. Bedrooms[2] | 2 | 2(equiv) | 3 | 3(equiv) | 4 | 4(equiv) |
| Total Depth, ft. | 7 | 7 | 7 | 7 | 7 | 7 |
| Depth Below Grade, ft. | 4 | 4 | 4 | 4 | 4 | 4 |
| Influent, gpd | 6000 | 5291(max) | 8000 | 6069(max) | 10,000 | 7108(max) |
| Dike Slope (h:v) | 3:1 | 3:1 | 3:1 | 3:1 | 3:1 | 3:1 |
| Bottom Area, $ft^2$ | 676 | 36 | 1156 | 36 | 1764 | 36 |
| Bottom Dimen., ft. | 26x26 | 6x6 | 34x34 | 6x6 | 42x42 | 6x6 |
| Inside Dike $ft^2$ | 4624 | 2304 | 5776 | 2304 | 7056 | 2304 |
| Inside Dike Dimen. | 68x68 | 48x48 | 76x76 | 48x48 | 84x84 | 48x48 |
| Total Lagoon $ft^2$ | 8836 | 5476 | 10,404 | 5476 | 12,100 | 5476 |
| Outside Dimen., ft. | 94x94 | 74x74 | 102x102 | 74x74 | 110x110 | 74x74 |
| OPERATIONAL DATA: | | | | | | |
| Influent[3], gal/mo | 5286 | 5286 | 6063 | 6063 | 7099 | 7099 |
| Precip.[3], gal/mo | 4840 | 1782 | 6482 | 1783 | 8365 | 1786 |
| Runoff[3], gal/mo | 975 | 644 | 1108 | 643 | 1242 | 643 |
| Evaporation.[3], gal/mo | 6472 | 2384 | 8667 | 2386 | 11,184 | 2389 |
| Seepage[3], gal/mo | 4364 | 5339 | 4986 | 6122 | 5521 | 7166 |
| $BOD_5$ Lbs/ac/day[5] | 5.7 | 15.3 | 5.5 | 20.0 | 5.6 | 26.1 |
| Avg. Depth[4], ft. | 4.09 | 4.11 | 4.08 | 4.11 | 4.07 | 4.12 |
| Min. Depth[4], ft. | 4.04 | 4.11 | 3.92 | 4.11 | 3.87 | 4.11 |
| Max. Depth[4], ft. | 4.10 | 4.12 | 4.10 | 4.12 | 4.10 | 4.12 |
| Avg. Surface $ft^2$ | 2550 | 942 | 3420 | 942 | 4412 | 942 |
| Avg. Surf. $ft^2$ | 51x51 | 31x31 | 58x58 | 31x31 | 66x66 | 31x31 |
| STRESS CONDITIONS OPERATION: | | | | | | |
| Max. Depth[6], ft. | 4.11 | 4.45 | 4.42 | 4.47 | 4.42 | 4.49 |
| Min. Depth[7], ft. | 3.72 | 4.10 | 3.64 | 4.10 | 3.55 | 4.10 |

TABLE 4.10, CONTINUED.

[1] Based upon OSDH Bulletin No. 600 (1).

[2] Dwelling unit room/bedroom equivalency based upon Tulsa Census data regression analysis results: No. Bedrooms = (.525 x rooms) - .275.

[3] Average monthly values during second year of lagoon operation.

[4] During 25-year design life of facility.

[5] $BOD_5$ load during second year (maximum normal population density) per average surface acre assuming 30% $BOD_5$ reduction in septic tank from primary settling.

[6] Maximum depth resulting from 20-year maximum annual rainfall, reduced seepage and 50% greater than normal dwelling unit population density (see text).

[7] Minimum depth resulting from 20-year drought occurring in 24th year of operation with normal dwelling unit population density (see text).

design criteria. Surface $BOD_5$ loads to the state designed facilities remain roughly constant at approximately 5.5 lbs/ac/day for increasingly larger dwellings while these loads increase significantly for the lagoon model-designed facilties. The $BOD_5$ surface loads are based upon an assumed thirty percent $BOD_5$ reduction due to primary settling in the septic tank which is required as pretreatment for these facilities. Based upon recommended $BOD_5$ surface loads for this area (see Chapter II) surface $BOD_5$ loadings above recommended levels would only be expected for very large dwelling units, i.e., greater than approximately twelve rooms.

The increase in seepage from these facilities resulting from the smaller design could potentially result in ponding of seepage water outside the lagoon dikes under adverse climatic conditions. The potential for unacceptable risks to public health from exposure of individuals to the seepage water is a consideration which was not evaluated during the course of this research. However, passage of the lagoon water through the fine textured soils of which the lagoon dikes are constructed (approximately twenty-one feet laterally at a four-foot operating depth) would be expected to remove virtually all microorganisms, including viruses and pathogenic bacteria, from the lagoon water by adsorptive mechanisms. The quality of such seepage water should be evaluated by microbiological testing procedures, however, to determine pathogenic quality in subsequent investigations. Under normal circumstances, evapotranspiration of the seepage water from the soil surfaces and vegetation growing on the outsides of the lagoon dikes should circumvent any seepage water accumulation in these areas.

Design of onsite residential lagoons employing the relationships of the computer model can result in significant decreases in the size of these facilities relative to those designed under current state criteria resulting in savings in both construction costs, and land area requirements. However, due to the importance of the seepage component in their design, close attention must be given to selection of proper below grade depths for these facilties to assure optimum operating levels are maintained.

# CHAPTER V

# CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

The primary objective of this research was to identify important demographic, hydraulic and hydrologic variables affecting various components of lagoon water balances, with the goal of developing a computer design model for onsite residential lagoons more sensitive to the many sources of water balance variance. The research included close examination of thirty-three onsite residential lagoon systems plus two additional commercial systems. Households served by the residential lagoons were surveyed by questionaire to ascertain potential wastewater flow-related physical and social variables, as well as household water use habits. Each of the residential lagoon sites was visited on three separate occasions over a two-month period, to collect operational data, as well as household static water pressure and winter water consumption rates, which could be correlated with wastewater flows. The commercial facilities were studied for three and a half months to develop dike rainfall-runoff relationships.

In addition to the lagoon system examinations, neighborhood demographic change analysis, based upon selected census tracts in Tulsa, Oklahoma, was undertaken to determine predictable trends in household population and age characteristics during the twenty-year period 1960 through 1980. Predictive relationships developed from this analysis subsequently provided the basis for projecting long-term dwelling unit wastewater flow changes.

The median operating depth of the thirty-three surveyed lagoon systems was 3.75 feet which was approximately 1.25 feet below the design depth of five feet for most of these facilities. At the time the systems were examined, most facilities should have been operating at or near their design capacity. Subsequent determination of seepage influences on lagoon water balances indicate this below normal average operating depth was probably due to the effects of seepage through the lagoon dikes.

Tabulation of current maintenance conditions at the surveyed facilities suggests that, although fencing immediately surrounding these facilities is appropriate for safety and health considerations, such fencing is an inhibitor to proper maintenance. As a rule, unfenced systems were much more likely to be well maintained than those surrounded by fences, and vise versa.

The wastewater flow from residences served by the surveyed lagoons (determined from winter water consumption) averaged 63.5 gpcd, almost 20 gpcd higher than the average of nine previous studies upon which an EPA 45 gpcd recommended design figure for onsite systems is based. The larger figure for Tulsa area systems is due, in part, to the affects of the "baseline" household consumption of the large number of two-member households included in this study.

Although income, as such, was not included in the household survey and consequently not employed as a water consumption predictor, an indirect measure of income, dwelling unit heated floor area, was found to correlate loosely, although significantly, with increased dwelling unit water consumption. No statistically significant difference in per capita water consumption was found between site built houses and mobile homes based upon the limited data available.

Important predictors of wastewater flow rates included the number of dwelling unit occupants and their ages, the number of baths and showers taken per day, and loads of laundry washed. Dishwasher use and static water pressure at the residence were not of demonstrable importance. Toilet use frequencies were not included in the survey. Multiple regression analyses showed children from birth to nine years of age, and adults twenty years and over, used nearly equivalent quantities of water at 23.7 gpcd and 26.1 gpcd, respectively, while older children ten to nineteen years using nearly twice as much at 63.9 gpcd. Baseline household water use (independent of numbers and ages of occupants) was high at 88.6 gpcd, explaining the nearly 20 gpcd higher use of households without children versus households with children and helping to explain the higher Tulsa area use compared with other studies in view of the large number of two-member households included in the survey.

Desirable variables for predicting water use in designing lagoons are those which are not subject to change as the occupying household changes during the design life of the facility. Such predictors are identifiable physical characteristics of the dwelling unit including square footage, number of bedrooms, number of bathrooms, etc.

Unfortunately, none of these physical characteristics were found to bear statistically significant predictive relationships with household wastewater flows. Consequently, demographic change analysis was resorted to as a means of identifying trends in household change which could be employed to reduce the variance in predicting household wastewater flow rates.

The demographic change analysis was based upon longitudinal examination of data from selected Tulsa area census tracts from the 1960, 1970 and 1980 censuses. This analysis showed that age of neighborhood dwelling units was an excellent indicator of general trends in dwelling unit demographic composition. An inverse relationship was identified between family size and dwelling unit age. Predictable changes in the age composition of families were apparent with aging of the dwelling unit. This provided the basis for regression equations capable of predicting family size and age composition from dwelling unit age which could be coupled with the multiple regression relating wastewater flow rates to household age composition. Based upon average new dwelling unit population densities, the size and age composition of the initial occupying family could be predicted, as well as subsequent changes in that size and age composition, from which predictable changes in wastewater flow rates during the design life of the facility could be estimated.

Examination of two commercial lagoon facilities to determine quantifiable rainfall-runoff relationships applicable to lagoon dikes suggested a fair, general predictor of lagoon dike runoff (as a percent of rainfall) is average daily evaporation. A general and inverse relationship between average daily evaporation and percentage of dike precipitation runoff was identified which predicts runoff as approximately 100% during winter months when evaporation is characteristically low, declining to less than 20% during summer when evaporation potential is high. Although such a relationship disregards other factors influencing runoff such as rainfall intensity, soil moisture levels, soil type, vegetative cover, etc., it provides the generalized basis needed for the nonevent-oriented monthly water balance computation requirements of lagoon design model procedures.

Lagoon seepage during the course of the study averaged 317 gpd for the thirty-three facilities, varying greatly from 21 gpd to 556 gpd. Data collected from the thirty-three surveyed lagoon systems, as well as the two runoff lagoon sites, support the premise that bottom seepage from facilities in the Tulsa area is negligible and that seepage occurs almost totally through the lagoon dikes in the area lying below the water surface but above the level of the surrounding grade. No useful relationships between other lagoon physical or dimensional variables, including total dike area, wetted dike area, bottom area or soil classification were evident in the analyses. Since lagoon seepage is directly affected by vertical depth gains and losses above grade, it is directly influenced by quantities of incident and runoff precipitation.

The computer design model developed from analysis of the household survey, lagoon survey, and demographic change relationship data is based upon computation of acceptable water balances throughout the facilities' twenty-five year design life expectancies, assuming seven-foot overall depths and five-foot optimum operating depths. The design model reiterates to optimize operating depth at five feet, when possible, while maintaining a 3:1 or 2.5:1 side slope on the surrounding dikes. The minimum, default bottom design dimensions of six feet by six feet is set to correspond to an assumed minimum construction size utilizing a small dozer. The model can be modified for use in other geographical locations by changing climatic variables, including rainfall and pan evaporation rates and their monthly distributions, as well as probability distribution return periods, providing assumptions concerning seepage and neighborhood change are evaluated for acceptability in other locations.

Seepage through the lagoon dikes was found to be the most significant influence on the water balances of onsite lagoons in the Tulsa area compared with wastewater influents, precipitation, dike runoff or evaporation. As a result, seepage is the controlling factor in lagoon design, making it possible to control operating depth largely by varying the depth of the facility below the level of the surrounding grade. Facilities designed by the computer model to serve dwelling units in the Tulsa area ranging from four rooms (one-bedroom) to twelve rooms (six-bedroom) (with a four-foot below grade depth) were all sized at the thirty-six square foot (six-foot by six-foot) default bottom square footage. This design was determined to function properly under all stress conditions, including unusually high population densities, and both unusually wet and dry climatic conditions.

Examination of the operational data, compared with Oklahoma State Department of Health conventional designs based solely upon net evaporation potential, indicate seepage rates increase as wastewater flow rates from larger households increase, enabling the facility to compensate for serving larger dwelling units. The rate of seepage increase is roughly equivalent to the rate of increase of influent flows from the larger households. Because of the much smaller facility design, compared with designs based upon state criteria, water balance gains from incident and dike runoff precipitation are greatly reduced, making dissipation of the increased influent flows the only seepage rate increase needed to maintain normal lagoon water levels.

## Recommendations

The size of computer model-designed onsite residential lagoons is controlled primarily by the seepage rate component of the water balance equation and, correspondingly, by the vertical dike area above grade. While the volumes of seepage from the facilities are somewhat greater than would be the case for lagoons designed according to state criteria, because of the reduced inputs from incident and runoff precipitation (resulting from smaller catchment areas), the seepage is not proportionally increased. For example, the increase in seepage from the computer model-designed facility over that which would occur from facilities designed in strict accordance with state design criteria ranges from just under 1,000 gal/mo for a two-bedroom dwelling unit to approximately 1,650 gal/mo for a four-bedroom dwelling unit, corresponding to percentage increases of eighteen to thirty percent, respectively. While it is not likely that such increases in seepage, distributed around the dike circumference, would result in noticable accumulation, it is possible that, under extreme weather conditions, some ponding of seepage water may occur outside the dikes. Construction of test facilities,based upon the computer design criteria, should be carried out to enable evaluation of this potential problem and operation under drought conditions as well.

Although the pathogenic quality of any seepage water which might accumulate outside the dikes would likely not be of public health significance due to the long distance of seepage travel through the fine soils from which the dikes are constructed, this possibility should be investigated. At a four-foot operating depth, seepage water would travel through approximatley twenty-one feet of compacted clay soils. Numerous investigations have reported high removal rates of both bacterial and viral pathogens as wastewater travels through soils, with greatest reductions being associated with fine soils where adsorption potential is greater. Under most weather conditions, evapotranspiration from dike soil surfaces and covering vegetation would circumvent any wastewater ponding.

The computer design model is based upon the widely accepted seven-foot overall lagoon depth (five-foot water depth). The operating water level stability exhibited by the model-designed facilities during run iterations suggests that a *significant* reduction in this depth might be possible. Additional research investigation should be conducted to examine the operation of lagoons with five-foot overall depths, three feet of which would lie below grade (reserving a two-foot freeboard). Calculations of the model suggest that such a facility would normally maintain a three-foot depth and, likely, would not rise above approximately three and a half feet or fall below a three-foot minimum under adverse household density, rainfall or drought conditions. This would assure a one and a half foot freeboard under adverse conditions while still preventing the development of rooted aquatic vegetation. It would have the additional benefit of allowing lower dikes to be constructed and enable a shallower operating depth, thus presenting less potential hazard to children who might gain access to the facility. With this design configuration it might also be possible to reduce the size of the facility again, if dike seepage ponding is found not to be a problem from the reduced lagoon size. Total overall dimensions for a five-foot deep lagoon could thus be reduced to 3,136 square feet (56' x 56') under this configuration, rather than the 5,476 square feet (74' x 74') currently designed by the model.

Additional investigation of factors influencing the seepage component of the water balance equation should also be carried out to refine the relationship between the seepage rate and the area of dike exposed to seepage. This model simply relates seepage to vertical rise in lagoon level, without regard to the area of dike through which the seepage occurs. Logically, however, the lagoon dike offers some control in the rate of seepage which is not addressed by the regression model resulting from this research, i.e., although the seepage equation developed from this research is acceptable for application to small residential facilities, it would predict unacceptably large quantities of seepage from large lagoons. The modifying influence of chemical, physical and biological clogging mechanisms on seepage rate control from these facilities should be investigated.

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# APPENDICES

A. Excerpts from OSDH Bulletin No. 600, Residential Sewage Disposal.

B. 1. Residential Lagoon Study Questionaire.
   2. Cover Letter for Questionaire, December 5, 1982.
   3. Follow-up Letter, January 4, 1983.
   4. Field Data Sheet.

C. Rainfall Isohyetal Distribution Maps.

D. Design Model Computer Program Listing.

## A. Excerpts from OSDH Bulletin No. 600, Residential Sewage Disposal.

### 6. REQUIREMENTS FOR INDIVIDUAL RESIDENTIAL LAGOONS

Plans for individual residential lagoons must be approved by the Department prior to construction. Total retention lagoons may be used on a lot of 2-1/2 acres or more where the percolation rate exceeds 45 minutes per inch. This minimum lot size requirement does not apply to lots in plats filed prior to January 1, 1974. Lagoons or alternative systems approved by the Department shall be required on lots with a percolation rate of more than 60 minutes per inch. However, alternative systems may only be employed after the owner follows the procedures and requirements of Section 7 of these Rules. No residential lots of less than 2½ acres shall be approved for an individual residential lagoon. However, any existing residence having a failing absorption field may be approved for a lagoon or alternative system when additional lateral lines cannot be installed or will not be effective. Lagoons shall meet or exceed the following construction standards:

6.1 Lagoon Location.

6.1.1 The lagoon system shall be at least 50 feet from any water well or domestic surface water supply. The distance shall be measured horizontally from the center line of the nearest dike. When elevation indicates a potential danger to a domestic water supply, the minimum distance shall be 100 feet. The lagoon shall be at least 15 feet from water lines.

6.1.2 The outside base of the lagoon dike shall be at least 50 feet from any dwelling, other than the property owner's dwelling, and at least 10 feet from the property line and other buildings.

6.1.3 Lagoons shall not be located where vegetation, timber or terrain could interfere with prevailing wind action or shade the lagoon during daylight hours.

6.2 Lagoon Design.

6.2.1 Wastes treated by a lagoon shall first pass through a septic tank which has been constructed in accordance with Section 3 of these Rules.

6.2.2 Residential lagoons shall be designed for total retention of wastes (accounting for normal rainfall and evaporation in the area) and shall not include an outfall.

6.2.3 The shape of all cells shall be uniform, essentially square or rectangular, and not contain islands or peninsulas.

6.2.4 The total depth of the lagoon shall be at least seven (7) feet and accomodate a maximum liquid waste depth of five (5) feet.

6.2.5 Inlet lines shall discharge onto a concrete slab, at least two feet square, located in the center of the lagoon. Inlet lines shall be supported and anchored.

6.2.6 The bottom of the lagoon shall be level and free of vegetation.

6.2.7 Residential lagoon systems must be designed by a Registered Professional Engineer, Registered Professional Sanitarian or Registered Land Surveyor.

6.2.8 The dikes and bottom shall be of impervious, thoroughly compacted material.

6.2.9 For gravity flow systems, the top of the dike shall be at least six inches (6") below the floor elevation of the house. For lift pump systems, a backflow device shall be installed between the pump and lagoon.

6.2.10 Dikes shall be constructed with a slope of no more than three (3) feet horizontal to one foot vertical (3:1).

6.2.11 Dikes shall be seeded or sodded and maintained with short grasses for erosion control.

6.2.12 Dikes shall be of sufficient height to divert surface runoff. The outer edge of all dikes shall be at least one foot above the surrounding terrain.

6.2.13 For gravity flow systems, the bottom of the lagoon shall be at least six (6) feet below the outlet from the septic tank.

6.2.14 The lagoon area shall be surrounded by a fence. Fencing must provide protection from access equivalent to the protection afforded by a five foot high, six barbed wire fence.

6.2.15 The lagoon shall have a sign, with letters at least one inch high, which states that the installation is a sewage lagoon.

6.3 Maintenance. The owner of the lagoon shall be responsible for proper maintenance to prevent mosquito problems and other nuisances.

## FINDING THE DIMENSIONS OF A SQUARE LAGOON

A. First, find the acres of surface area. Divide the volume of annual household wastewater by net evaporation times 27,200 (one acre-inch of water).

Household wastewater produced per year is about:
2 bedroom home - 72,000 gallons per year (6000 gal./month x 12)
3 bedroom home - 96,000 gallons per year (8000 gal./month x 12)
4 bedroom home - 120,000 gallons per year (10,000 gal./month x 12)

Net evaporation equals Pan Evaporation minus Annual Rainfall.

B. The square feet of surface area equals acres of surface area times 43,560 (square feet per acre)

C. The length of one side of the lagoon at the water level is the square root of the number of square feet of surface area.

D. Then, to find the length of one side at the bottom of a lagoon with a 3:1 slope:

4' depth - subtract 24 feet from the length of one side at the water level.
5' depth - subtract 30 feet from the length of one side at the water level.

### EXAMPLE

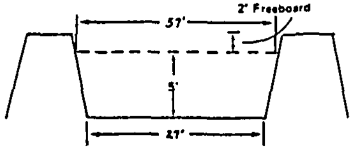
To design a lagoon (having a five foot liquid depth and dikes sloped 3:1) for a three bedroom home located in Pauls Valley, Oklahoma:

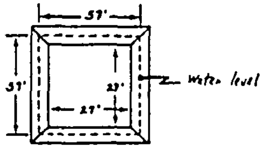
A. 96,000 gallons / (83 inches per year - 36 inches per year) x 27,200 = .0750938 acres of surface area;

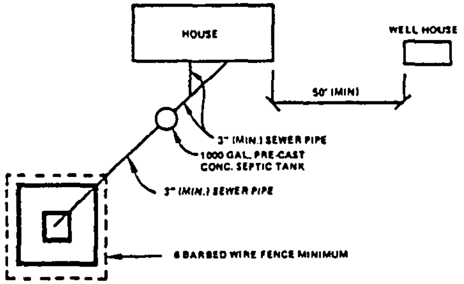
B. .0750938 x 43,560 = 3,271 square feet of surface area;

C. Square root of 3,271 = 57 feet, the length of one side at the water level;

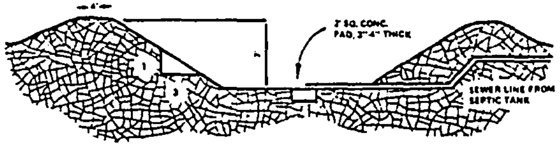
D. 57' - 30' = 27 feet, the length of one side of the bottom of the lagoon.







TYPICAL RESIDENTIAL SEWAGE LAGOON



CROSS SECTION OF LAGOON

B-1.

System ID____________________

# RESIDENTIAL LAGOON STUDY QUESTIONAIRE

Name:________________________________ Street Address:____________________________

Mailing Address (if different):________________________________________________

City:____________________________ Zip Code____________________________

*Upon receiving this completed questionnaire we will include your lagoon in the study.* Your response to these questions will help to determine those characteristics of your household which directly affect water use and, consequently, wastewater flow into your lagoon. If you anticipate using significant quantities of water during January and February outside, or in any manner in which it will not enter your lagoon, e.g., car washing, landscape watering, livestock watering, etc., please provide an explanatory note in the remarks area at the bottom of this form.

1. Type of dwelling: ☐ site built house ☐ mobile home ☐ manufactured home
2. What is the approximate square footage of your dwelling _____________ sq. ft.
   (If unknown, may we measure the outside dimensions? ______)
   Does this figure include a garage? __________
3. What was the original cost of your residence? ________________
   In what year was it purchased? 19___
   Did this cost include your lot or land? ________
   How much land? _____________acres
4. What is the source of your water? ☐ private well ☐ public water system
5. Please indicate the number of each type of room your dwelling contains.

| | |
|---|---|
| _____Living Room(s), den(s), and Family Room(s) | _____Full bathroom(s) (lavoratory, toilet, tub) |
| _____Bedroom(s) | _____3/4 Bathroom(s) (lavoratory, toilet, shower) |
| _____Kitchen(s) | _____1/2 Bathroom(s) (lavoratory, toilet) |
| _____Dining Room(s) | _____Others: Please specify________________ |
| _____Utility Room(s) | _____ ____________________________ |

6. Do you have a garbage disposer? ________
7. Do you have an automatic dishwasher? ________
   If yes, how many loads of dishes do you wash per week? _______
8. Do you have a clothes washer? ________
   If yes, approximately how many loads of laundry do you wash per week? ________
9. Approximately how many baths are taken per week in your household? ________
   How many showers? ________
10. Please indicate the ages of all persons residing in your dwelling.

| | | |
|---|---|---|
| Person 1 _____ | Person 4 _____ | Person 7 _____ |
| Person 2 _____ | Person 5 _____ | Person 8 _____ |
| Person 3 _____ | Person 6 _____ | Person 9 _____ |

Remarks:____________________________________________________________

______________________________________________________________________

## B-2. Cover Letter for Questionaire, December 5, 1982.

TULSA CITY-COUNTY HEALTH DEPARTMENT

4616 East 15th • 918 744-1000
Tulsa, Oklahoma 74112

December 15, 1982

81-2125

Mr. J. R. Goodnight
1075 East Admiral Place
Tulsa, Oklahoma 74116

Dear Mr. Goodnight:

Records on file with this Department indicate that your residence is one of many served by an individual sewage disposal lagoon (pond) constructed since 1976. This and other types of individual residential sewage disposal systems are sized according to approximate expected waste flows based upon the number of bedrooms contained in the dwelling. As you might expect, because of the considerable differences among house types, appliances, families and life styles, the actual waste flows vary greatly among dwellings with the same number of bedrooms. As a result, proper functioning of these small waste disposal systems is often adversely affected by unexpected large or small waste flows.

This Department, in cooperation with the Departments of Civil Engineering and Sociology of the University of Oklahoma, is undertaking a study of small Tulsa area sewage disposal systems, particularly lagoons. This research is being carried out in the hope of developing more accurate design criteria for small systems based upon other structural and demographic characteristics of households which show promise as better indicators of variations in sewage flow from individual residences. Individual sewage disposal lagoons or ponds provide a unique opportunity to study these differences since the flows can be determined by measuring changes in lagoon water depths.

At this time we are seeking Tulsa area residents such as yourself whose dwellings are served by this type of system to participate in this research program. Should you elect to participate, your only commitment as a lagoon owner would be to complete and return the attached brief, postage paid survey form and give us permission to visit your property three times (around the first of January, February, March, 1983) for approximately fifteen minutes. During those visits we would (1) read your water meter if your residence is served by a public water supply, (2) measure the water level and surface area of the lagoon (a measuring device would be driven into the lagoon bank or bottom and removed at the end of the survey ) and (3) measure your water pressure at an outside hydrant. All work would be completed outside the residence by Department personnel with proper identification and, in most cases, driving easily identifiable Department vehicles. You would not need to be home at these times but field personnel would stop to notify you before entering your property to take the measurements.

Every effort will be made to insure the study will be completed with no inconvenience to its participants. All information gathered during the survey will be held absolutely confidential and once the field measurements are completed, all references to individual names and addresses will be removed from the data.

Your participation in this study will be sincerely appreciated and will be invaluable in helping to establish better criteria both for designing future small sewage disposal systems and for helping to mitigate problems with existing ones. All participants will be mailed summaries of the research results upon completion of the study. If you have any questions regarding the program, I encourage you to contact me between the hours of 8:00 a.m. and 5:00 p.m., Monday through Friday at 744-1000 extension 222.

Sincerely,

Gary D. Woodruff
Office of Planning and Research

GDW:lg
Enclosure

TULSA CITY-COUNTY HEALTH DEPARTMENT

4616 East 15th • 918 744-1000
Tulsa, Oklahoma 74112

TO: Tulsa Area Residential Lagoon Owners

FROM: Gary D. Woodruff
Office of Planning and Research

DATE: January 4, 1983

Dear Lagoon Owner:

You were recently mailed a letter and questionnaire requesting your participation in a study of residential lagoon systems by this Department in cooperation with the University of Oklahoma. Since we have not as yet received a response from you we wish to appeal to you once again for your help. The number of systems available for inclusion in the research is relatively limited making it even more important that we recruit as many as possible.

Let me reiterate that all information obtained will be held strictly confidential and all measurements taken will be obtained outside your residence by Department personnel. Please take time to complete the questionnaire and allow us to include your system in the research. An extra copy of the questionnaire has been included with this letter. Although all questions included on the form are important, if you have chosen not to participate because you consider some of the questions to be too personal, please complete those which you feel are less objectionable so that your system can be included.

Your help will be greatly appreciated both by this office and future lagoon system owners. Thank you.

B-3. Follow-up Letter, January 4, 1983

B-4.

## RESIDENTIAL LAGOON STUDY FIELD DATA

System I.D.____________________ Final Inspection Date_______________

Name________________________________________________

Address______________________________________________

Site Built_________ Mobile Home_________ Manufactured Home _________

Sq. Mi._________ C.T._________ Inside Dike Dim.____Ft. X ____Ft.

Lagoon Condition: (circle appropriate responses):

1. Operating Level: (1) low (2) below norm. (3) normal (4) above normal (5) high
2. Fence Condition: (1) good (2) fair (3) poor (4) unfenced
3. Dike Vegetation: (1) mowed (2) unmowed
   (1) grass (2) weeds (3) trees (4) brush
4. Aquatic Vegetation: (1) none (2) limited (3) moderate (4) abundant
5. Dike Erosion: (1) none (2) slight (3) moderate (4) severe

Initial Measurements:

Date______________ Time________ Water Surface Dim.____Ft. X ____Ft.

Water Level_________Ft. Static water pressure____________psig

Water Meter Reading______________

End of First Month:

Date______________ Time________

Water Level_________Ft. Static water pressure____________psig

Water Meter Reading______________

End Second Month:

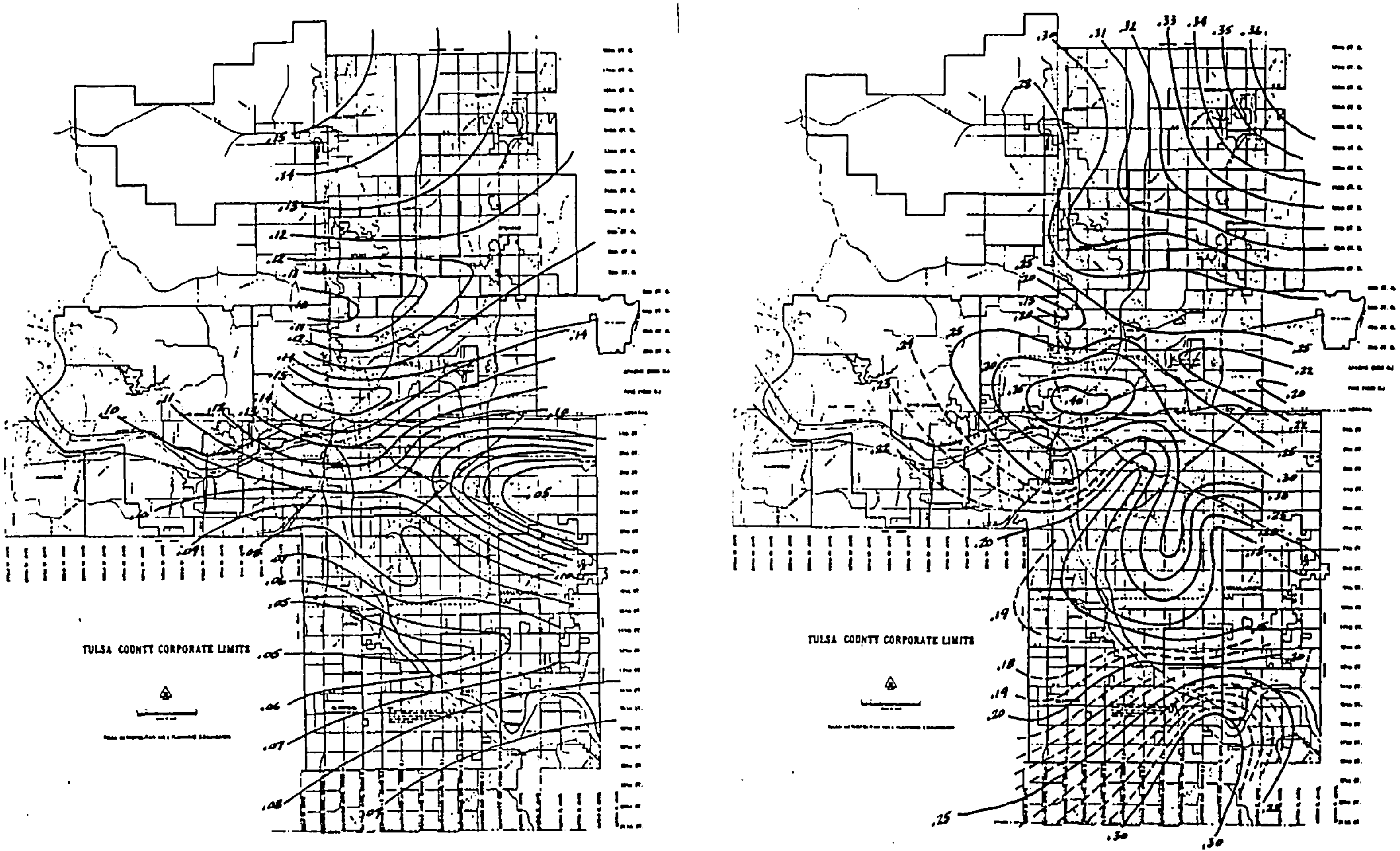
Date______________ Time________

Water Level_________Ft. Static water pressure____________psig

Water Meter Reading______________

Remarks:______________________________________________

____________________________________________________

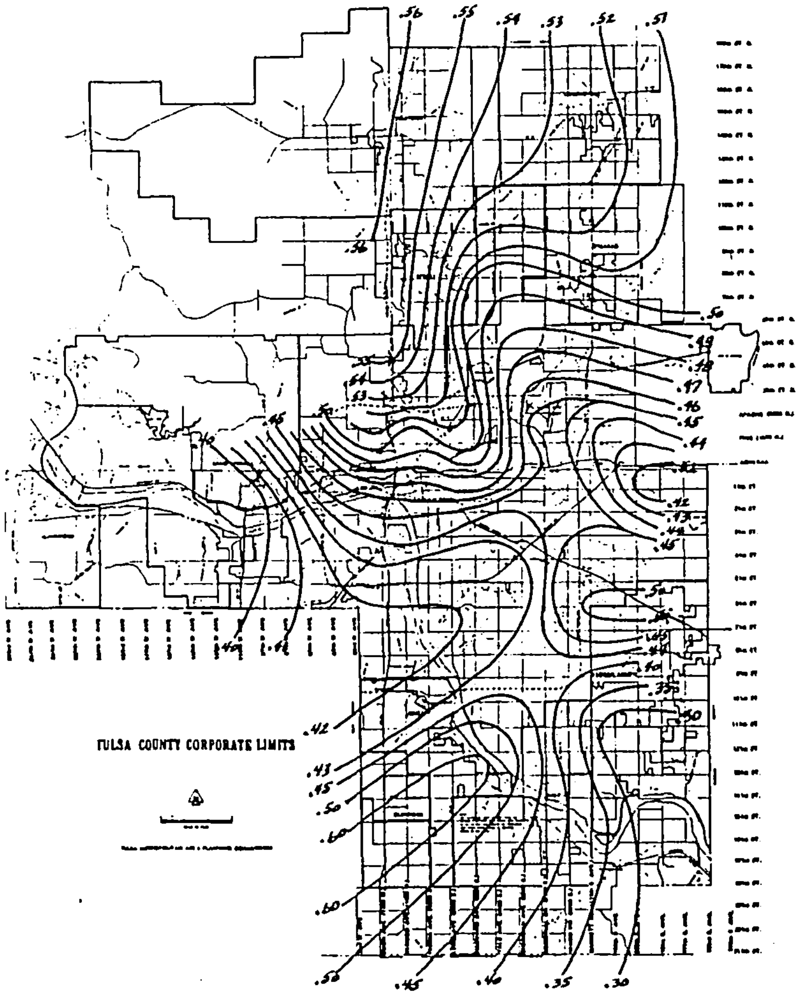


SNOWFALL WATER EQUIVALENT
1-19-83

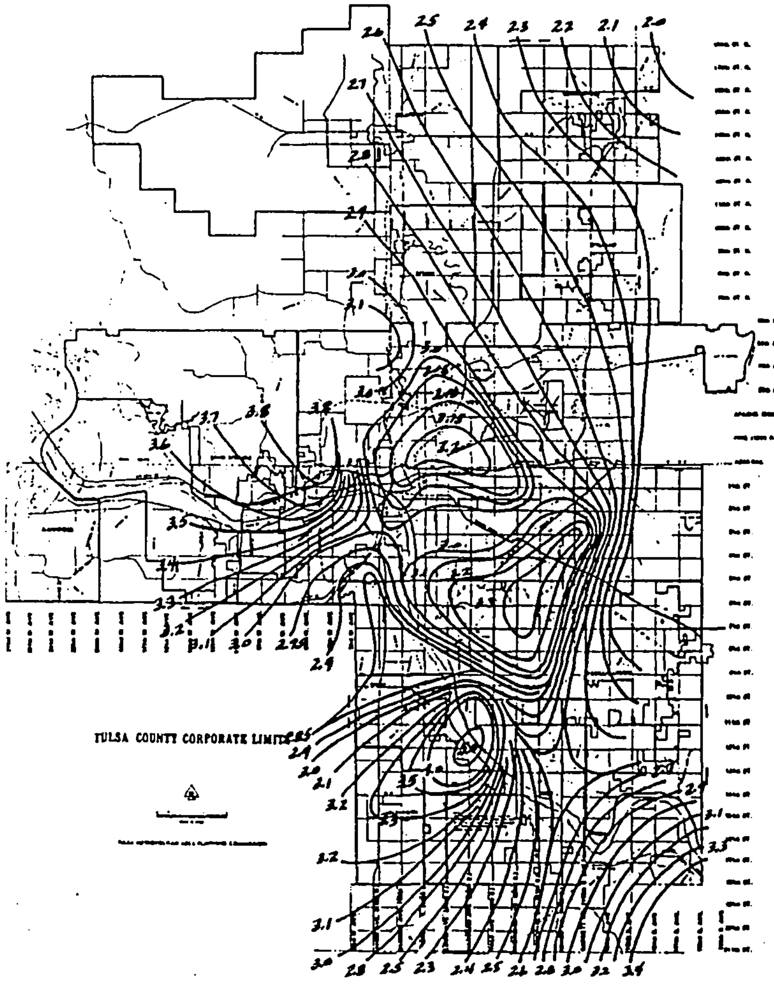
SNOWFALL WATER EQUIVALENT
1-21-83

C. Rainfall Isohyetal Distribution Maps.

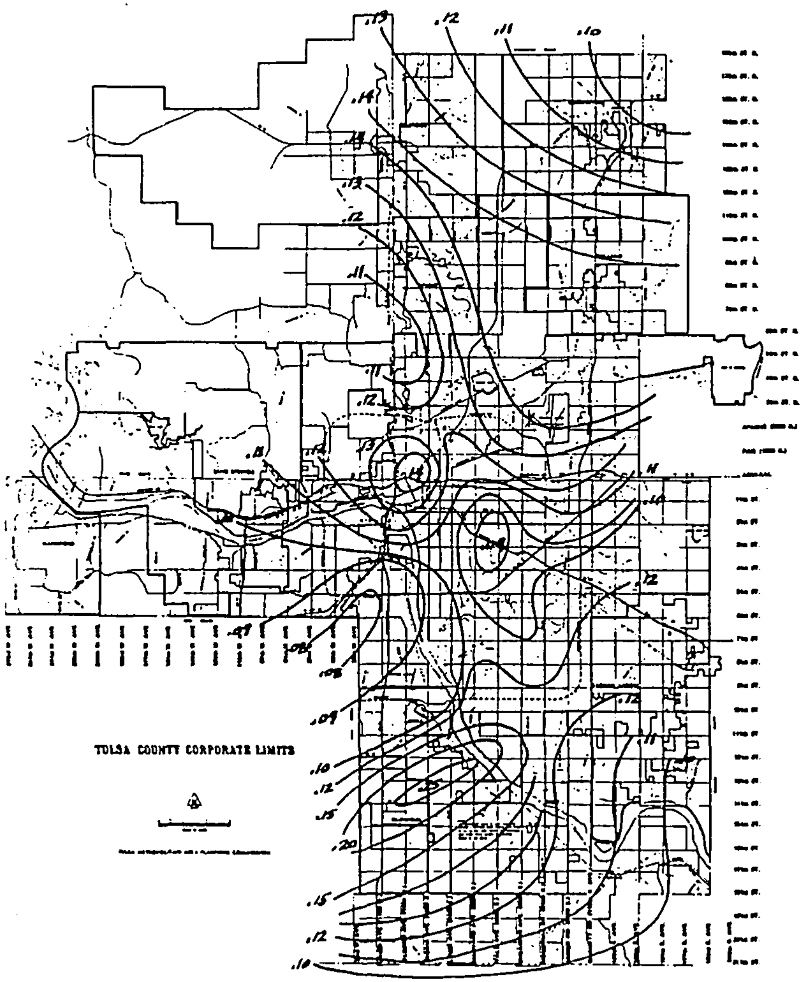
RAIN / SNOW
1-26-83



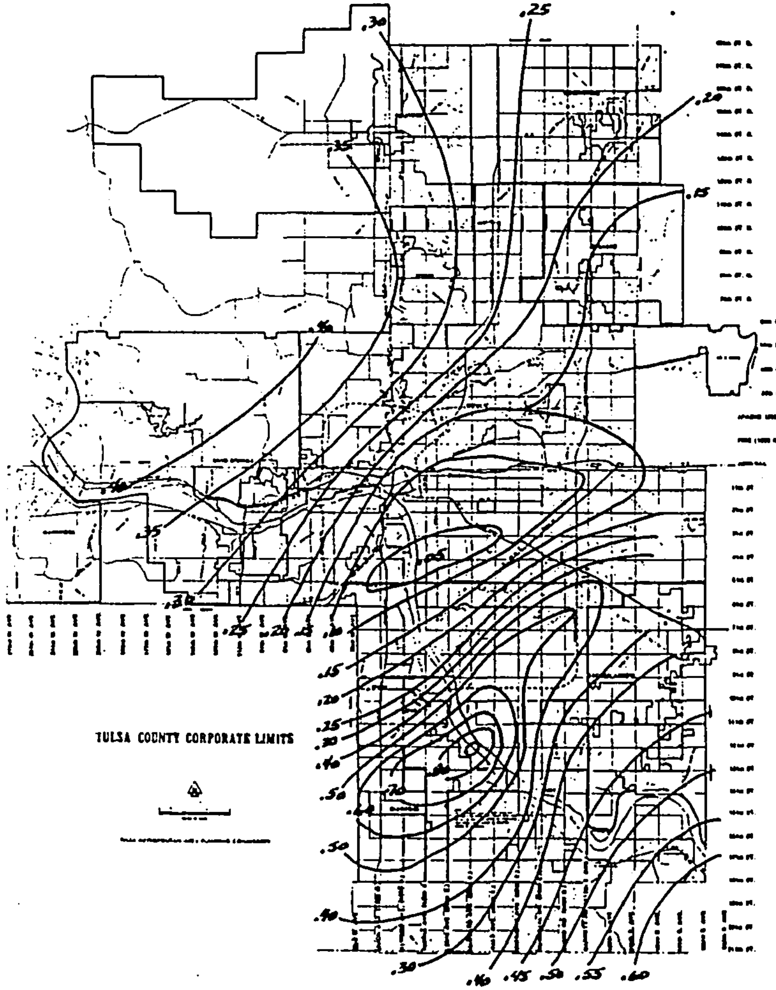
RAIN
1-28-83 to 2-1-83



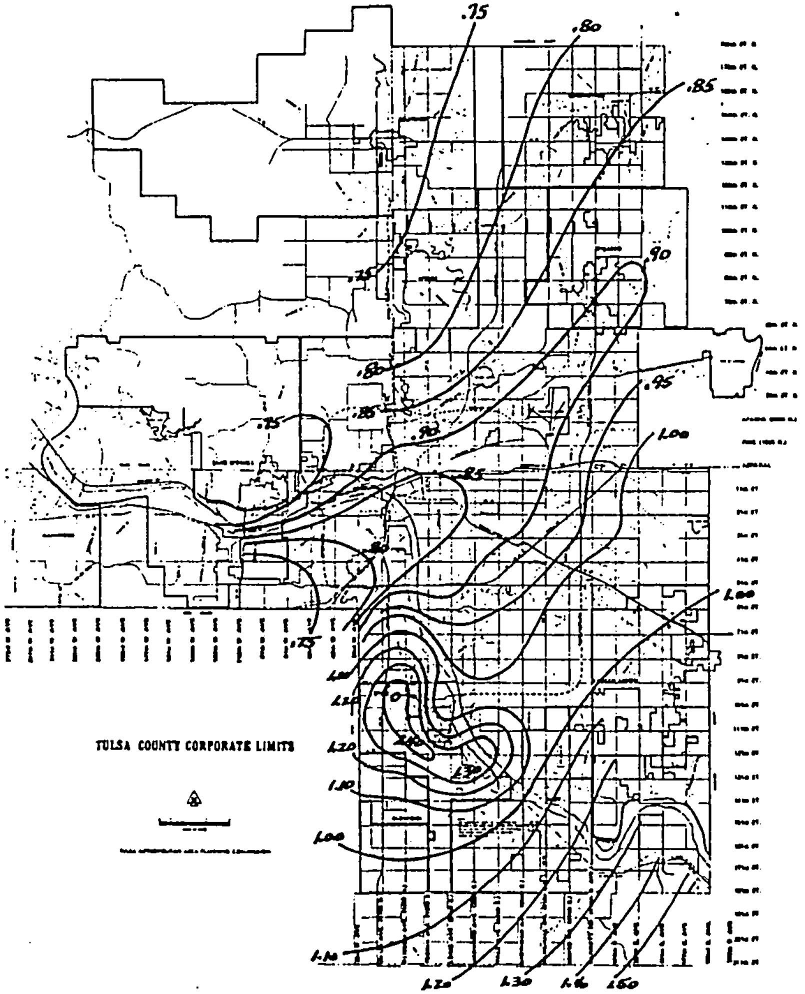
SNOWFALL WATER EQUIVALENT
2-4-83



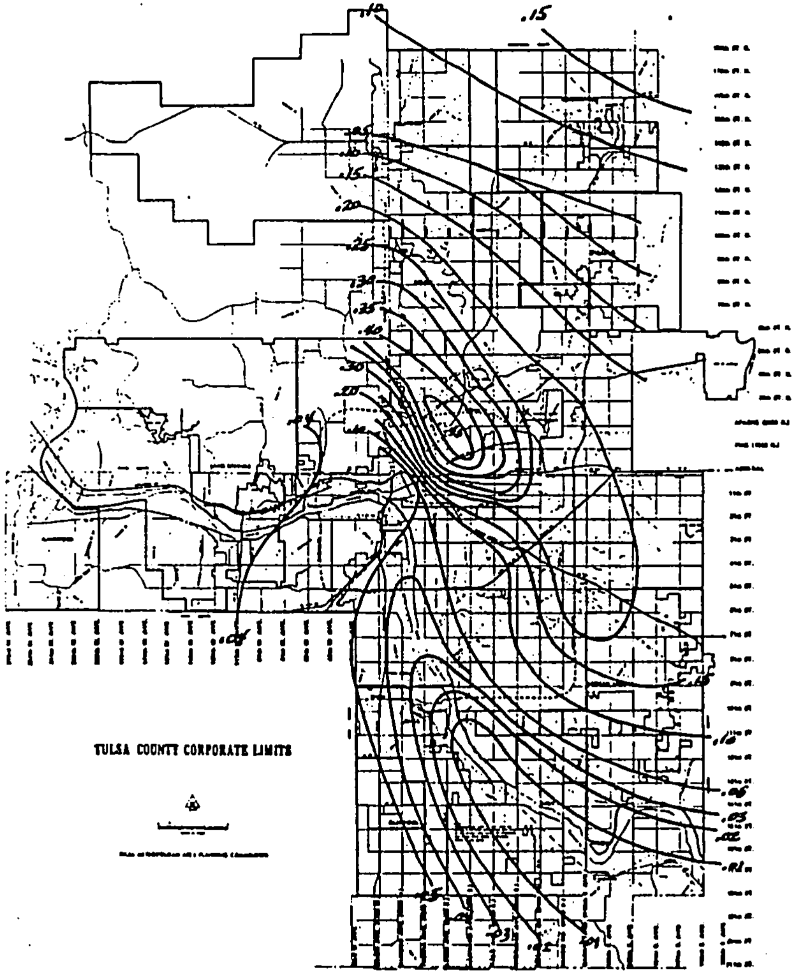
RAIN 2-9-83



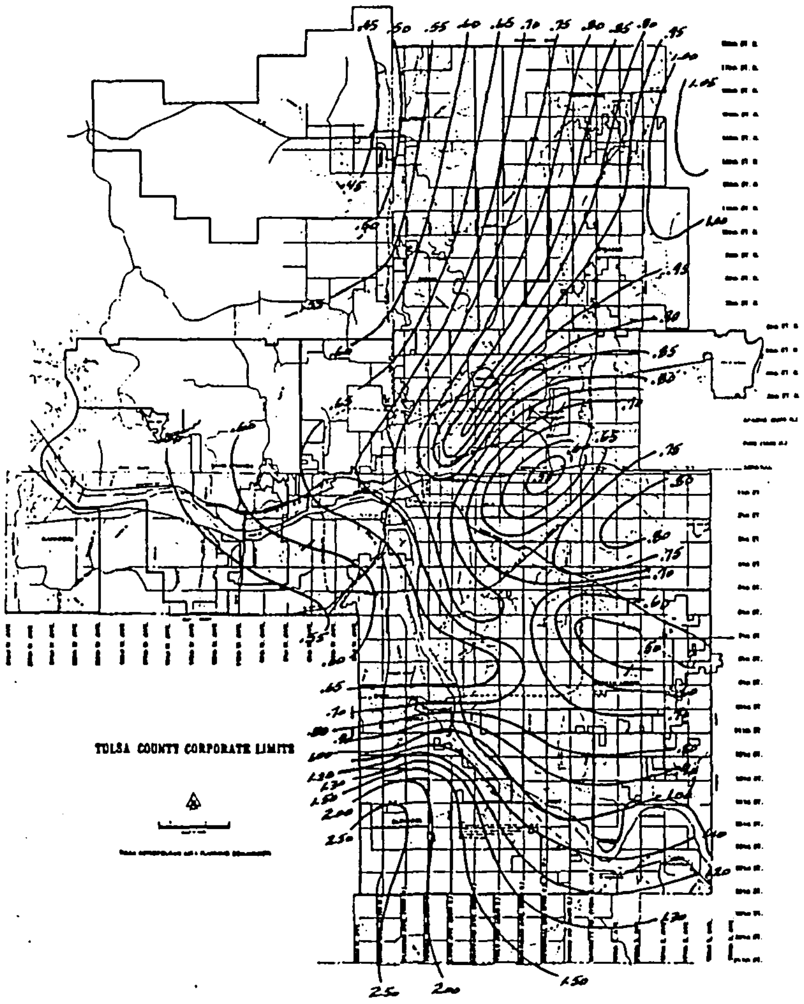
RAIN 2-20-83 to 2-21-83



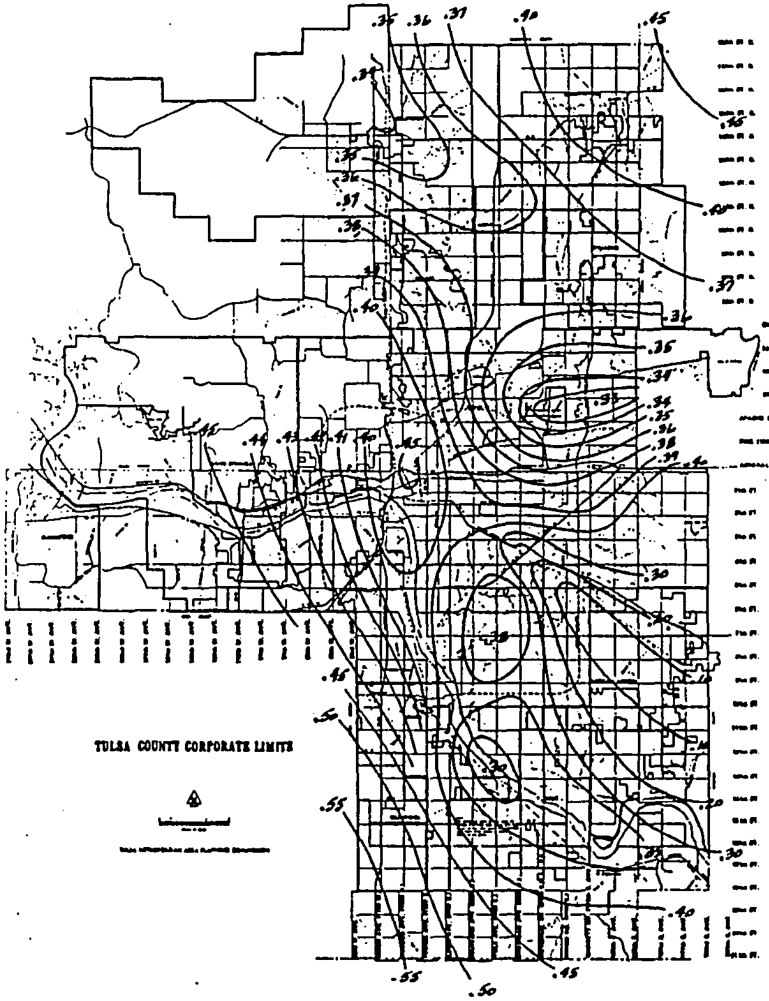
RAIN 2-24-83



RAIN
3-4-83 TO 3-6-83



RAIN
3-19-83



## D. Design Model Computer Program Listing.

```
10 'Program written by Gary D. Woodruff, Officer of Planning and Research, Tulsa
20 'City-County Health Department, 4616 E. 15th Street, Tulsa, Oklahoma 74112."
30 'April 12, 1985
40 'M Basic. Osborne Executive Computer: Adaptable to IBM PC XT by changing
50 'page control character line 100 from (26) to (12).
60 'Model requires 12 x 4 data matrix B:PPCTEVAP.DA to run.
70 'Key local climatic variables which require changing for model use in other"
80 'geographic locations include the data matrix distributions and variables"
90 'contained in lines 650-710."
100 PAGE$ = CHR$(26):PRINT PAGE$
110 PRINT "                    THIS IS AN ONSITE RESIDENTIAL LAGOON DESIGN PROGRAM"
120 PRINT
130 PRINT "                 DO YOU WANT TO SEE A BRIEF EXPLANATION OF THIS PROGRAM?"
140 PRINT
150 INPUT "                                Enter      [Y]es     or    [N]o    ",ABSTR$
160 IF ABSTR$<>"Y" THEN GOTO 530
170 PRINT
180 PRINT "     This program will design an onsite residential lagoon to serve a"
190 PRINT " single family dwelling optimized for demographic and environmental"
200 PRINT " conditions characteristic to the Tulsa, Oklahoma metropolitan area."
210 PRINT " By changing values of key variables and those in the accompanying"
220 PRINT " data file the program can by employed to design systems for other"
230 PRINT " geographic locations provided the user accepts the applicability"
240 PRINT " of seepage rate and demographic change assumptions in those areas.  "
250 PRINT "     Required keyboard input data include 1) number of dwelling"
260 PRINT " unit rooms (census definition, e.g., excludes utility rooms, bath-"
270 PRINT " rooms, hallways, half rooms, etc.), 2) desired inside dike slope"
280 PRINT " (either 1:3 or 1:2.5) and 3) the depth of the lagoon below the "
290 PRINT " surrounding grade ( i.e., depth of lagoon bottom below the lowest"
300 PRINT " ground level immediately outside the surrounding dikes)."
310 INPUT "             Press Return Key to Continue......", ACON$
320 IF ACON$<>"" GOTO 310
330 PRINT PAGE$
340 PRINT "     The program internally calculates average number of dwelling"
350 PRINT " unit occupants, ages the occupants over the design life, and computes"
360 PRINT " corresponding wastewater flows. Rainfall is applied directly to the "
370 PRINT " water surface as well as to the dikes where runoff is calculated. "
380 PRINT " Evaporation is computed and finally seepage loss is subtracted from"
390 PRINT " the facility to determine a monthly water balance.  All lagoon water"
400 PRINT " balance gains and losses are controlled by monthly distributions,"
410 PRINT " and/or regression equations, as appropriate. The program iterates"
420 PRINT " to achieve an optimum maximum water level of 5 feet during the"
430 PRINT " 25-year design life when possible.  The minimum bottom design default"
440 PRINT " size is 6' x 6'.  After optimum design is computed, a printed copy"
450 PRINT " of the design can be requested along with a 25-year water balance"
460 PRINT " for the facility."
470 PRINT "     A final option of applying household and environmental stress"
480 PRINT " conditions to the lagoon to test the adequacy of the design is also"
490 PRINT " allowed and is more fully explained during the program run.  Complete"
500 PRINT " program documentation and developmental theory are available."
510 INPUT "           Press Return Key To Run Program.....",BCON$
520 IF BCON$<>"" GOTO 510
530 OPTION BASE 1
540 PRINT PAGE$
550 DIM A(12,4)
560 OPEN "I",1,"B:PPCTEVAP.DA"
570 INPUT #1,R,C
580 FOR I=1 TO 12
590 FOR J=1 TO 4
600 INPUT #1, A(I,J)
610 LET Q=0;R=0
620 NEXT J
630 NEXT I
640 CLOSE
650 M2=36.5          'MEDIAN ANNUAL RAINFALL
660 MM2=59           '95% ANNUAL PROBABILITY LEVEL RAINFALL
670 LM2=24.5         '5% ANNUAL PROBABILITY LEVEL RAINFALL
680 EVP=68.6         'MEDIAN ANNUAL PAN EVAPORATION
690 EVP1=63          'ANNUAL PAN EVAP FOR 5% RAINFALL YEAR
700 EVP2=72.8        'ANNUAL PAN EVAP FOR 95% RAINFALL YEAR
710 LAKE=.712        'LOCAL LAKE EVAPORATION COEF.
720 D1=2
730 DO=2             'INITIAL LAGOON DEPTH
740 FOR I=1 TO 25          'YEAR COUNTER
750 IF COPY$="Y" THEN LET Z=Z+1
760 IF I>1 GOTO 810
770 LET L=L+1
780 IF L>1 THEN GOTO 810
790 PRINT PAGE$
800 INPUT "ENTER NUMBER OF ROOMS IN DWELLING UNIT:    ", R1
810 LET PO = (-.02*I)+(.000231*I^2)+.8152          'POP PER ROOM
820 LET P7=(.469 * PO)-.178+.38               'ADJUSTED POP PER ROOM
830 LET P2 = P7*R1                            'H.H. POPULATION
840 LET P3=(((-2.336*I)+(.0652*I^2)-(.000643*I^3)+41.5)*P2)/100 'HH POP 0-9
850 LET P4=(((1.077*I)-(.0558*I^2)+(.0007*I^3)+11.18)*P2)/100  'HH POP 10-19
860 LET P5=(((1.345*I)-(.014*I^2)+46.88)*P2)/100       'HH POP >= 20
870 LET V1=((((63.86*P4)+(23.7*P3)+(26.1*P5)+88.6)*.1337))*365/12  'FLOW/MO.
880 IF I=1 THEN IF L>1 THEN GOTO 1080
890 IF I>1 GOTO 1240
900 IF L>1 THEN GOTO 1250
910 LET B1%=(.525*R1)-.275           'EST. NO. BEDROOMS
920 LET B1=B1%
930 IF D1<2 THEN IF D1>6 THEN GOTO 1000
940 IF B1=1 THEN LET B2=49
950 IF B1=2 THEN LET B2=49
960 IF B1=3 THEN LET B2=100
970 IF B1=4 THEN LET B2=144
980 IF B1>=5 THEN LET B2=196
990 PRINT "ASSUMED INITIAL BOTTOM DESIGN FT2 = "B2
1000 PRINT
1010 PRINT
1020 PRINT
1030 PRINT "INDICATE DESIRED INSIDE DIKE SLOPE:"
1040 INPUT "ENTER EITHER .4 FOR 1:2.5  OR  .33 FOR 1:3:    ",P1
1050 IF P1<>.33 AND P1<>.4 THEN PRINT CHR$(7): GOTO 1040
1060 IF P1=.33 THEN LET S1=.33333333#
1070 IF P1=.4 THEN LET S1=.4
1080 LET S2=((B2^.5)+(2*(D1*(1/S1))))^2             'INITIAL SURFACE FT2
1090 LET V2=(D1*((B2+S2)+((B2*S2)^.5)))/3    'INITIAL VOLUME
1100 IF I=1 THEN IF L>1 THEN GOTO 1240
1110 PRINT PAGE$
1120 PRINT "Lagoon seepage has been found to occur primarily through the dikes
1130 PRINT "when water levels rise above the surrounding grade.  Bottom seepage,
1140 PRINT "in most cases, is negligible.  In order for this model to correctly"
1150 PRINT "estimate seepage, it is necessary to enter the depth of the"
1160 PRINT "proposed facility from its bottom to the lowest point on the sur-"
1170 PRINT "rounding grade (outside the dikes).  For most lagoons on level"
1180 PRINT "sites this will be approximately 3.5'.  For lagoons to be built"
1190 PRINT "on relatively steep slopes it may be near zero (0.0')."
1200 PRINT "If the exact depth above grade cannot be predetermined, estimate."
1210 PRINT
1220 INPUT "ENTER THE DEPTH IN FEET AND TENTHS, (EXAMPLE: 3.4):    ",D8
1230 PRINT PAGE$
1240 FOR K=1 TO 12
1250 LET DO=D1
1260 LET X1=A(K,3)*M2     'INCHES RAINFALL FOR NORMAL MONTH
1270 LET X2=(A(K,2)*(EVP*LAKE)/12)*S2  'NORMAL EVAP FOR MO. FT3
1280 IF S2=0 THEN LET X2=0
1290 LET X3=(X1/12)*S2      'FT3 TOTAL DIRECT RAINFALL TO H2O SURFACE
1300 IF I<>2 THEN LET X5=M2        'NORMAL YEAR ANNUAL RAINFALL
1310 LET S3=(((B2^.5)+(2*((1/S1)*7)))^2)-S2      'DIKE AREA ABOVE WATER LINE-FT2
1320 LET X7=((X1/12)*S3)*A(K,4)              'DIKE RUNOFF FT3
1330 LET X4=V1+X3+X7-X2             'POTENTIAL NET WATER BALANCE CHANGE/MONTH
1340 LET VOL2=V2
1350 LET V2=V2+X4                   'POTENTIAL NEW VOLUME AT END OF MONTH
1360 IF V2<0 THEN LET V2=0
1370 'NEW DEPTH = D1
1380 IF P1=.33 THEN LET  D1=(.43679*((V2+(.055556*((B2^.5)^3)))^.33333))-(.16667*B2^.5)
1390 IF P1=.4 THEN LET D1=(.49324*((V2+(.066667*((B2^.5)^3)))^.33333))-(.2*B2^.5)
1400 IF D1>=D8 THEN LET D3=D1-D8
```

```
1410 LET M3=(.9736*((D3*12)/A(K,1)))-.0354        'SEEPAGE IN./DAY
1420 IF M3<0 THEN LET M3=0
1430 LET SPGFT=(M3/12)*A(K,1)          'SEEPAGE - FT/MO
1440 LET SURF1=((B2^.5)+(D1*((1/S1)*2)))^2  'SURF AREA W/O SEEPAGE
1450 LET D1=D1-SPGFT                   'DEPTH AFTER SEEPAGE
1460 LET SURF2=((B2^.5)+(D1*((1/S1)*2)))^2  'SURF AREA AFTER SEEPAGE
1470 LET SURFAV=(SURF1+SURF2)/2
1480 LET M4=(M3/12*A(K,1))*SURFAV          'SEEPAGE FT3
1490 LET D3=0
1500 LET X4=V1+X3+X7-X2-M4            'NEW WATER BALANCE CHANGE/MONTH
1510 LET V2=VOL2
1520 LET V2=V2+X4
1530 LET DEPTH=(D1+D0)/2
1540 IF COPY$="Y" THEN GOTO 1650
1550 IF K>1 THEN IF I>=1 THEN GOTO 1640
1560 IF I=1 THEN IF K=1 THEN PRINT "  The monthly water balance for this facility given the "
1570 IF I=1 THEN IF K=1 THEN PRINT USING " design bottom area of #### sq. ft. would be as follows:";B2
1580 PRINT
1590 IF K=1 THEN PRINT USING "     YEAR ##";I
1600 PRINT
1610 PRINT" MONTH   INFLUENT   RAINFALL   RUNOFF     EVAP     SEEPAGE      DEPTH"
1620 PRINT"   no.      ft3        ft3       ft3       ft3       ft3          ft"
1630 PRINT
1640 PRINT USING "   ##      ####       ####      ####      ####      ####         #.##";K;V1;X3;X7;X2;M4;DEPTH
1650 IF D1<0 THEN LET D1=0
1660 IF 09<>1 THEN GOTO 1760
1670 LET T5=7.48052
1680 LET V9=V1*T5
1690 LET X3=X3*T5
1700 LET X7=X7*T5
1710 LET X2=X2*T5
1720 LET M4=M4*T5
1730 IF K=1 THEN LPRINT USING "     YEAR ##";I
1740 LPRINT USING"     ##     #####      #####     #####     #####     #####        #.##";K;V9;X3;X7;X2;M4;DEPTH
1750 IF 09=1 THEN GOTO 1810
1760 IF D0>=D9 THEN LET D9=D0
1770 LET Z1=Z1+1
1780 IF D9 <=5! THEN IF Z1=36 THEN GOTO 1980
1790 IF Q>=1 THEN IF Z1=36 THEN GOTO 2240
1800 IF D0 > 5! THEN GOTO 2160
1810 LET S2=((B2^.5)+(D1*((1/S1)*2)))^2    'NEW SURFACE AREA - FT2
1820 LET V2=(D1*((B2+S2)+((B2*S2)^.5)))/3     'NEW VOL. @ END MO. - FT3
1830 IF 09=1 THEN D3=0:GOTO 1910
1840 IF D1 >6.5 THEN LET B2=((B2^.5)+1!)^2
1850 IF D1>6.5 THEN PRINT I,K
1860 IF D1>6.5 THEN LET I=0
1870 IF D1>6.5 THEN LET K=0
1880 IF D1>6.5 THEN PRINT "LAGOON DEPTH EXCEEDED 6 FT; INITIAL DESIGN INCREASED"
1890 IF D1>6.5 THEN PRINT "NEW BOTTOM DESIGN FT2 = " B2
1900 IF D1>6.5 THEN GOTO 720
1910 NEXT K
1920 IF COPY$="Y" THEN IF Z=4 THEN LPRINT CHR$(12):Z=0
1930 NEXT I
1940 IF 09=1 THEN GOTO 2840
1950 CLOSE
1960 RESET
1970 GOTO 5520
1980 LET R=R+1
1990 IF R>=1 THEN IF Q>=1 THEN GOTO 2240
2000 PRINT PAGE$
2010 PRINT "MAXIMUM WATER DEPTH BELOW 5.0 FT., INITIAL DESIGN DECREASED"
2020 LET I=0:K=0:B2=((B2^.5)-1!)^2
2030 LET B2%=B2:LET B2=B2%
2040 IF B2=36 THEN LET DFALT=6:B9=6
2050 IF DFALT=6 THEN PRINT
2060 IF DFALT=6 THEN PRINT"   DESIGN BOTTOM DIMENSIONS SET TO MINIMUM ALLOWABLE 6'X 6' DEFAULT SIZE."
2070 IF DFALT=6 THEN PRINT
2080 IF DFALT=6 THEN PRINT
2090 IF DFALT=6 THEN PRINT "   NOTE: If greater lagoon operating depth is needed or desired,"
2100 IF DFALT=6 THEN PRINT "         the depth below grade must be increased."
2110 IF DFALT=6 THEN PRINT
2120 IF DFALT=6 GOTO 2280
2130 LET Z1=0:D3=0:D9=0
2140 PRINT USING "NEW BOTTOM DESIGN FT2 = ####";B2
2150 GOTO 720
2160 LET Q=Q+1
2170 IF Q>=1 THEN IF R=>1 THEN GOTO 2240
2180 PRINT PAGE$
2190 PRINT "MAXIMUM DEPTH GREATER THAN 5.0 FT., INITIAL DESIGN INCREASED"
2200 LET I=0:K=0:B2=((B2^.5)+1!)^2
2210 LET Z1=0:D3=0:D9=0
2220 PRINT USING "NEW BOTTOM DESIGN = #### SQ. FT.";B2
2230 GOTO 720
2240 PRINT PAGE$
2250 PRINT "             OPTIMUM BOTTOM DESIGN HAS BEEN DETERMINED"
2260 LET B9=B2^.5
2270 PRINT USING "DESIGN BOTTOM DIMENSIONS ARE ## X ## FT.";B9;B9
2280 PRINT USING "DESIGN BOTTOM AREA IS #### SQ. FT. ";B2
2290 PRINT USING "MAXIMUM OPERATING DEPTH UNDER NORMAL CONDITIONS WILL BE: #.## FT.";D9
2300 PRINT
2310 PRINT
2320 PRINT "          DO YOU WANT A PRINTED COPY OF THE DESIGN RESULTS?"
2330 PRINT
2340 INPUT "                    ENTER  [Y]es  or  [N]o"; COPY$
2350 IF COPY$="Y" THEN GOTO 2370
2360 IF COPY$="N" THEN GOTO 2840
2370 LPRINT "                     ONSITE RESIDENTIAL LAGOON DESIGN"
2380 LPRINT
2390 LPRINT
2400 LPRINT "          INPUT DATA SPECIFIED:"
2410 LPRINT
2420 IF P1=.33 THEN LET SLOPE=3!
2430 IF P1=.4 THEN LET SLOPE=2.5
2440 LPRINT USING "               Number of Dwelling Unit Rooms:           ##";R1
2450 LPRINT USING "               Inside Dike Slope:                       1:#.#";SLOPE
2460 LPRINT USING "               Lagoon Depth Below Grade:                #.# FT.";D8
2470 LPRINT
2480 LPRINT "          MODEL ASSUMPTIONS:"
2490 LPRINT
2500 LPRINT "             Design Life of Facility:               25 Yrs."
2510 LPRINT "             Total Facility Depth:                   7 Ft."
2520 LPRINT "             Maximum Normal Water Depth:             5 Ft."
2530 LPRINT "             Dike Freeboard:                         2 Ft."
2540 LPRINT "             Median Annual Rainfall:              36.5 In."
2550 LPRINT "             Median Annual Lake Evap.:            48.8 In."
2560 LPRINT "             Initial Water Depth:                    2 Ft."
2570 LPRINT
2580 LPRINT "          DESIGN RESULTS:"
2590 LPRINT
2600 LPRINT USING "               Maximum Normal Depth:                    #.## Ft.";D9
2610 LET B9%=B9
2620 LET B2%=B9%^2
2630 LPRINT USING "               Design Bottom Area:                      #### Sq. Ft.";B2%
2640 IF P1=.33 THEN LET T1=B9%+42:T2=T1^2
2650 IF P1=.4 THEN LET T1=B9%+35:T2=T1^2
2660 LPRINT USING "               Design Bottom Dimensions:             ## x ## Ft.";B9;B9
2670 IF DFALT=6 THEN LPRINT "                     (Bottom dimensions set to minimum allowable default size)."
2680 LPRINT USING "               Inside Dike (Top) Area:                  #### Sq. Ft.";T2
2690 LPRINT USING "               Inside Dike Dimensions:               ## x ## Ft.";T1;T1
2700 IF P1=.33 THEN LET T3=B9%+30:T4=T3^2
2710 IF P1=.4 THEN LET T3=B9%+25:T4=T3^2
2720 LPRINT USING "               Water Surface Area @ 5 Ft.:              #### Sq. Ft.";T4
2730 LPRINT USING "               Surface Dimensions @ 5 Ft.:           ## x ## Ft.";T3;T3
2740 LET SBOD=(P2*.17)/(T4/43560!)*.7
2750 LPRINT USING "               Surface BOD Load @ 5 Ft.:                ##.# Lbs/ac/day";SBOD
2760 LPRINT
2770 LPRINT
2780 LPRINT CHR$ (12)
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2790 LPRINT "************************** 25 YEAR MONTHLY WATER BALANCE **********************"
2800 LPRINT "     MONTH     INFLUENT     PRECIP.     RUNOFF     EVAP.     SEEPAGE     DEPTH"
2810 LPRINT "      no.       gal/mo       gal/mo     gal/mo    gal/mo     gal/mo       ft.
2820 LET Q9=1:I=0:K=0:D3=0
2830 GOTO 720
2840 PRINT PAGE$
2850 PRINT "     This residential lagoon system has been designed to serve the "
2860 PRINT USING "average dwelling unit with ## rooms given the listed assumptions.";R1
2870 PRINT "The design assumes average dwelling unit demographic characteristics"
2880 PRINT "and normal climatic conditions for the Tulsa metropolitan area."
2890 PRINT
2900 PRINT "     The adequacy of the system's design capacity to accommodate"
2910 PRINT "hydraulic conditions (e.g. excessive rainfall or influent flows,"
2920 PRINT "drought, etc.) significantly different from normal without over-"
2930 PRINT "flowing or operating too shallow may be tested by the following "
2940 PRINT "supplemental stress analysis."
2950 PRINT
2960 PRINT "     DO YOU WANT TO PERFORM A STRESS ANALYSIS ON THE DESIGN CAPACITY"
2970 PRINT "                      OF THIS LAGOON SYSTEM?"
2980 PRINT
2990 INPUT "                      [Y]es    or    [N]o    ",STRES$
3000 IF STRES$="Y" THEN GOTO 3020
3010 IF STRES$="N" THEN GOTO 1950
3020 PRINT PAGE$
3030 PRINT " DESIGN STRESS SIMULATION CAN INCLUDE THREE ANALYSES:
3040 PRINT
3050 PRINT "     1)  Extreme Climatic Conditions:
3060 PRINT
3070 PRINT "          - Excessive rainfall equivalent to the 20-year exceedence event"
3080 PRINT "               (i.e., 95% rainfall probability level; one year in 20"
3090 PRINT "               may experience equivalent or greater total rainfall)"
3100 PRINT "               with corresponding decreased evaporation applied."
3110 PRINT
3120 PRINT "               Excess rainfall is applied in the 2nd (critical) year."
3130 PRINT
3140 PRINT "          - 20-year annual drought (i.e., 5% rainfall probability level;"
3150 PRINT "               one year in 20 may receive equivalent or less total rain-"
3160 PRINT "               fall) with corresponding increased evaporation applied."
3170 PRINT
3180 PRINT "               Drought conditions are applied in the (critical) 24th"
3190 PRINT "               year of operation."
3200 PRINT
3210 INPUT "     Press Return Key To Continue.........",CCCN$
3220 IF CCCN$<>"" GOTO 3210
3230 PRINT
3240 PRINT "     2) Unusually High Dwelling Unit Population Density:"
3250 PRINT
3260 PRINT "          - Household population is increased by 50% above model cal-"
3270 PRINT "               culated normal level for the design life of the facility."
3280 PRINT
3290 PRINT "     3) Unusually Low Facility Seepage Rate:"
3300 PRINT
3310 PRINT "          - Facility seepage rate is reduced to the lower 95% confidence"
3320 PRINT "               band of surveyed lagoon rates (i.e., one facility in 20"
3330 PRINT "               may exhibit an equivalent or lower rate of seepage)."
3340 PRINT
3350 PRINT "               Seepage rate is reduced for the design life of the facility."
3360 PRINT
3370 PRINT "        SELECT STRESS SIMULATIONS TO BE APPLIED TO THIS DESIGN:"
3380 PRINT
3390 INPUT "            1) Climatic                      [Y]es   or   [N]o   ",CLIM$
3400 PRINT
3410 INPUT "            2) Increased Pop. Density        [Y]es   or   [N]o   ",POP$
3420 LET Z=0
3430 PRINT
3440 INPUT "            3) Reduced Seepage Rate          [Y]es   or   [N]o   ",SEEP$
3450 PRINT PAGE$
3460 D1=2
3470 D0=2
3480 LET L=0
3490 FOR I=1 TO 25        'YEAR COUNTER
3500 IF PRNT$="Y"THEN LET Z=Z+1
3510 LET L=L+1
3520 LET P0 = (-.02*I)+(.000231*I^2)+.8152        'POP PER ROOM
3530 LET P7=(.469 * P0)-.178+.38              'ADJUSTED POP PER ROOM
3540 IF POP$="Y" THEN LET P7=P7*1.5
3550 LET P2 = P7*R1                                'H.H. POPULATION
3560 LET P3=(((-2.336*I)+(.0652*I^2)-(.000643*I^3)+41.5)*P2)/100 'HH POP 0-9
3570 LET P4=(((1.077*I)-(.0558*I^2)+(.0007*I^3)+11.18)*P2)/100  'HH POP 10-19
3580 LET P5=(((1.345*I)-(.014*I^2)+46.88)*P2)/100      'HH POP >= 20
3590 LET V1=((((63.86*P4)+(23.7*P3)+(26.1*P5)+88.6)*.1337))*365/12  'FLOW/MO.
3600 IF I=1 THEN IF L>1 THEN GOTO 3630
3610 IF I>1 GOTO 3660
3620 IF L>1 THEN GOTO 3660
3630 LET S2=((B2^.5)+(2*(D1*(1/S1))))^2              'INITIAL SURFACE FT2
3640 LET V2=(D1*((B2+S2)+((B2*S2)^.5)))/3     'INITIAL VOLUME
3650 IF I=1 THEN IF L>1 THEN GOTO 3660
3660 FOR K=1 TO 12
3670 LET D0=D1
3680 IF CLIM$="Y" THEN GOTO 3710
3690 LET X1=A(K,3)*M2                'INCHES R.F. FOR NORMAL MONTH
3700 LET X2=(A(K,2)*(EVP*LAKE)/12)*S2  'NORMAL MONTHLY EVAP - FT3
3710 IF CLIM$="N" THEN GOTO 3800
3720 IF I<>2 THEN IF I<>24 THEN LET X1=A(K,3)*M2
3730 IF I=2 THEN LET X1=MM2*A(K,3)   'R.F. INCHES/MONTH - 2ND YEAR
3740 IF I=24 THEN LET X1=LM2*A(K,3)    'R.F. INCHES /MONTH - 24TH YEAR
3750 IF I<>2 THEN IF I<>24 THEN LET X2=(A(K,2)*(EVP*LAKE)/12)*S2  'NORMAL MONTHLY EVAP - FT3
3760 IF I=2 THEN LET X8=(A(K,2)*(EVP1))*LAKE    '2ND YR. EVAP/MO. - INCHES
3770 IF I=2 THEN LET X2=(X8/12)*S2    '2ND YR. EVAP/MONTH - FT3
3780 IF I=24 THEN LET X8=(A(K,2)*EVP2)*LAKE      '24TH YR. EVAP/MO. - INCHES
3790 IF I=24 THEN LET X2=(X8/12)*S2            '24TH YR. EVAP/MONTH - FT3
3800 LET X3=(X1/12)*S2       'FT3 TOTAL DIRECT RAINFALL TO H2O SURFACE
3810 IF I=24 THEN IF CLIMS$="Y" THEN LET X5=LM2        '24TH YEAR DROUGHT RAINFALL
3820 LET S3=(((B2^.5)+(2*((1/S1)*7)))^2)-S2      'DIKE AREA ABOVE WATER LINE-FT2
3830 LET X7=((X1/12)*S3)*A(K,4)            'DIKE RUNOFF FT3
3840 LET X4=V1+X3+X7-X2       C   'POTENTIAL NET WATER BALANCE CHANGE/MONTH
3850 LET VOL2=V2
3860 LET V2=V2+X4                   'POTENTIAL NEW VOLUME AT END OF MONTH
3870 IF V2<0 THEN LET V2=0
3880 'NEW DEPTH = D1
3890 IF P1=.33 THEN LET  D1=(.43679*((V2+(.055556*((B2^.5)^3)))^.33333))-(.16667*B2^.5)
3900 IF P1=.4 THEN LET D1=(.49324*((V2+(.066667*((B2^.5)^3)))^.33333))-(.2*B2^.5)
3910 IF D1>D8 THEN LET D3=D1-D8
3920 IF D3<0 THEN LET D3=0
3930 LET M3=(.9736*((D3*12)/A(K,1)))-.0354          'SEEPAGE IN./DAY
3940 LET CON4=.0545249*SQR(1+(1/31)+(((D3*12)/A(K,1))-.2435)^2/.34573)*2.048      '95% LOWER CONF. BAND FOR SPS.
3950 IF SEEP$="Y" THEN LET M3=M3-CON4
3960 IF M3<0 THEN LET M3=0
3970 LET SPGFT=(M3/12)*A(K,1)                 'SEEPAGE - FT/MO
3980 LET SURF1=((B2^.5)+(D1*((1/S1)*2)))^2  'SURF AREA W/O SEEPAGE
3990 LET D1=D1-SPGFT     'DEPTH AFTER SEEPAGE
4000 LET SURF2=((B2^.5)+(D1*((1/S1)*2)))^2   'SURF AREA AFTER SEEPAGE
4010 LET SURFAV=(SURF1+SURF2)/2
4020 LET M4=((M3/12)*A(K,1))*SURFAV     'SEEPAGE - FT3/MO
4030 LET D3=0
4040 LET X4=V1+X3+X7-X2-M4             'NEW WATER BALANCE CHANGE/MONTH
4050 LET V2=VOL2
4060 LET V2=V2+X4
4070 LET DEPTH=(D1+D0)/2               'AVG DEPTH FOR MONTH
4080 LET D0=D1
4090 IF PRNT$ = "Y" THEN GOTO 4230
4100 IF K>1 THEN IF I=>1 THEN GOTO 4220
4110 IF I=1 THEN IF K=1 THEN PRINT "   The monthly water balance for this facility given the "
4120 IF I=1 THEN IF K=1 THEN PRINT " calculated design bottom area and the selected stress conditions "
4130 IF I=1 THEN IF K=1 THEN PRINT " would be as follows:"
4140 PRINT
4150 IF K=1 THEN PRINT USING "     YEAR ##";I
4160 IF I=2 THEN IF CLIM$="Y" THEN PRINT "  (20-Year Annual Rainfall Applied)
4170 IF I=24 THEN IF CLIM$="Y" THEN PRINT "  (20-Year Drought Applied)
4180 PRINT
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4190 PRINT "  MONTH    INFLUENT   RAINFALL   RUNOFF    EVAP    SEEPAGE     DEPTH"
4200 PRINT "   no.       ft3         ft3       ft3      ft3      ft3         ft"
4210 PRINT
4220 PRINT USING "    ##       ####       ####        ####       ####       ####      #.##";K;V1;X3;X7;X2;M4;DEPTH
4230 IF DO>DMAX THEN LET DMAX=DO
4240 IF I=2 THEN IF K=1 THEN LET DMIN=DO
4250 IF I>1 THEN IF DO<DMIN THEN LET DMIN=DO
4260 IF D1<0 THEN LET D1=0
4270 IF PRNT$<>"Y" GOTO 4360
4280 LET T5=7.48052
4290 LET V9=V1*T5
4300 LET X3=X3*T5
4310 LET X7=X7*T5
4320 LET X2=X2*T5
4330 LET M4=M4*T5
4340 IF K=1 THEN LPRINT USING "                                        YEAR ##";I
4350 LPRINT USING"     ##      #####      #####      #####      #####      #####      #.##";K;V9;X3;X7;X2;M4;DEPTH
4360 LET B2=((B2^.5)+(D1*((1/B1)*2)))^2      'NEW SURFACE AREA - ft2
4370 IF PRNT$="Y" THEN GOTO 5450
4380 IF DO<6.5 THEN  IF INC$="Y" THEN GOTO 4490
4390 IF DO<6.5 THEN IF INC$<>"Y" THEN GOTO 4580
4400 IF DO>6.5 THEN IF INC$="Y" THEN GOTO 4470
4410 PRINT "    Lagoon depth has exceeded 6.5 feet leaving only 0.5 foot of freeboards."
4420 PRINT "  Do you want the design bottom area of this facility increased to accommodate"
4430 PRINT "  these stress conditions with a maximum 6.5 foot depth?"
4440 PRINT
4450 INPUT "                    Enter    [Y]es    or    [N]o    ", INC$
4460 IF INC$<>"Y" GOTO 5450
4470 LET B2=((B2^.5)+1!)^2
4480 IF DO>6.5 GOTO 4560
4490 PRINT "  The design bottom area has been increased to accommodate these stress "
4500 PRINT "  and remain below 6.5 feet maximum depth."
4510 PRINT USING "  The new design bottom area of the facility is #### sq. ft.";B2
4520 PRINT
4530 INPUT "      Press Return Key to Continue...", CON$
4540 IF CON$<>""GOTO 4530
4550 GOTO 4910
4560 LET I=0:K=0:D3=0:DMAX=0:DMIN=0
4570 GOTO 3460
4580 IF DO>2 THEN IF DEC$="Y" THEN GOTO 5450
4590 IF DO>2 THEN IF DEC$<>"Y" THEN GOTO 5450
4600 IF DO<2 THEN IF DEC$="N" THEN GOTO 5450
4610 IF DO<2 THEN IF DEC$="Y" THEN GOTO 4720
4620 IF DO<2 THEN IF I<=1 THEN GOTO 5450
4630 PRINT "  Lagoon depth has fallen below 2.0 feet.  Do you want the bottom design area"
4640 PRINT "of this facility decreased to accommodate these stress conditions while "
4650 PRINT "maintaining a minimum 2 foot depth if possible?"
4660 INPUT"              Enter    [Y]es    or    [N]o     ",DEC$
4670 IF DEC$="Y"THEN PRINT
4680 IF DEC$="Y" THEN IF B9=<6 THEN PRINT "  Design bottom area is already reduced to allowable minimum."
4690 IF DEC$="Y" THEN PRINT
4700 IF DEC$="Y" THEN IF B9=<6 THEN LET DEC$="N"
4710 IF DEC$<>"Y" GOTO 5450
4720 IF SQR(B2)<=6 THEN GOTO 4750
4730 LET B2=((B2^.5)-1!)^2
4740 IF DO<2 THEN GOTO 4820
4750 PRINT "   The design bottom area has been decreased to accommodate these stress "
4760 PRINT "  conditions by retaining a minimum 2.0 foot depth if possible."
4770 PRINT USING "    The new design bottom area is #### sq. ft.";B2
4780 PRINT
4790 INPUT "    Press Return Key to Continue....",CCON$
4800 IF CCON$<>"" GOTO 4790
4810 GOTO 4910
4820 LET I=0:K=0:D3=0:DMAX=0:DMIN=0
4830 GOTO 3460
4840 PRINT
4850 PRINT "                              STRESS ANALYSIS RESULTS:"
4860 PRINT
4870 PRINT USING "                   Maximum Depth Attained:                #.## Ft.";DMAX
4880 PRINT USING "                   Minimum Remaining Freeboard:           #.## Ft.";(7-DMAX)
4890 PRINT USING "                   Minimum Depth Attained:                #.## Ft.";DMIN
4900 PRINT
4910 PRINT"                      DO YOU WANT A PRINTED COPY OF THIS ANALYSIS?"
4920 PRINT
4930 INPUT"                               ENTER    [Y]es    or    [N]o    ", PRNT$
4940 IF PRNT$<>"Y" GOTO 5500
4950 LPRINT"                       ONSITE RESIDENTIAL LAGOON STRESS ANALYSIS"
4960 LPRINT
4970 LPRINT
4980 FOR U=1 TO  5 :LPRINT :NEXT U
4990 LPRINT "             DESIGN SPECIFICATIONS:"
5000 LPRINT
5010 LPRINT USING "                         Number of Dwelling Unit Rooms:       4       ##";R1
5020 LPRINT USING "                         Inside Dike Slope:                          1:#.#";SLOPE
5030 LPRINT USING "                         Lagoon Depth Below Grade:                   #.# Ft.";DB
5040 LPRINT USING "                         Bottom Design Area:                        #### Sq. Ft.";B2
5050 LPRINT "                       Total Facility Depth:                         7 Ft."
5060 LPRINT "                       Dike Freeboard:                               2 Ft."
5070 LPRINT
5080 IF DEC$="Y" THEN LPRINT"                  NOTE: The bottom design area shown above for this facility"
5090 IF DEC$="Y" THEN LPRINT"                           reflects a decrease to accommodate the lower  operating"
5100 IF DEC$="Y" THEN LPRINT"                     depths resulting from these stress conditions."
5110 IF INC$="Y" THEN LPRINT"                  NOTE: The bottom design area shown above for this facility"
5120 IF INC$="Y" THEN LPRINT"                           reflects an increase to accommodate the greater operating"
5130 IF INC$="Y" THEN LPRINT"                           depths resulting from these stress conditions."
5140 LPRINT "             STRESS CONDITIONS APPLIED:"
5150 LPRINT
5160 IF CLIM$="Y"THEN LET ANS1$="Yes"
5170 IF CLIM$="N"THEN LET ANS1$="No"
5180 LPRINT "                     Extreme Climatic Conditions:"
5190  LPRINT USING "                        20-year Annual Rainfall (2nd yr.)        \ \";ANS1$
5200 LPRINT USING "                         20-year Drought (24th yr.)             \ \";ANS1$
5210 LPRINT
5220 LPRINT"                      High Dwelling Unit Population Density:"
5230 IF POP$="Y" THEN LET ANS2$="Yes"
5240 IF POP$="N" THEN LET ANS2$="No"
5250 LPRINT USING "                          150% of Normal Density (All Yrs.)       \ \";ANS2$
5260 LPRINT
5270 IF SEEP$="Y" THEN LET ANS3$="Yes"
5280 IF SEEP$="N" THEN LET ANS3$="No"
5290 LPRINT "                     Low Facility Seepage Rate:"
5300 LPRINT USING "                         Lower 95% Confidence Band (All Yrs.)     \ \";ANS3$
5310 LPRINT
5320 LPRINT "             STRESS ANALYSIS RESULTS:"
5330 LPRINT
5340 LPRINT USING "                         Maximum Depth Attained:                          #.##";DMAX
5350 LPRINT USING "                         Minimum Remaining Freeboard:                     #.##";(7-DMAX)
5360 LPRINT USING "                         Minimum Depth Attained:                          #.##";DMIN
5370 LPRINT CHR$(12)
5380 LPRINT "**************** 25 YEAR WATER BALANCE UNDER STRESS CONDITIONS ****************"
5390 LPRINT "     MONTH    INFLUENT    PRECIP.    RUNOFF    EVAP.    SEEPAGE    DEPTH"
5400 LPRINT "      no.      gal/mo     gal/mo     gal/mo   gal/mo    gal/mo      ft."
5410 LPRINT
5420 LET I=0:K=0:D3=0
5430 LET X3=0:X7=0:X2=0:M4=0
5440 GOTO 3460
5450 NEXT K
5460 IF PRNT$="Y" THEN IF Z=4 THEN LPRINT CHR$(12):Z=0
5470 NEXT I
5480 IF PRNT$="Y" THEN GOTO 5500
5490 GOTO 4840
5500 CLOSE
5510 RESET
5520 END
```