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Technical Report

# Septic System Maintenance Management

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Division of Water Pollution Control
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SEPTIC SYSTEM MAINTENANCE MANAGEMENT

## ABSTRACT

Traditionally, the maintenance of on-lot disposal systems has been the responsibility of the homeowner. This report examines the potential for management of on-lot systems by a municipal or regional mangement agency. Such management, because more frequent inspection and pumping of on-lot systems would occur, promises reduced ground and surface water pollution from on-lot systems. Furthermore, such an arrangement can reduce the costs of inspections and pumping on a per-system basis because of the economies of scale and mangement efficiencies possible. This report also estimates the annual fee required to support municipal septic system managment with and without the assumption by the municipal agency of all repair, replacement, and rehabilitation costs for the systems under its management. These latter costs are estimated by combining a statistical analysis of failures and repairs over the past 36 years in Amherst, MA and the reported costs for typical repair and replacement actions.

# 1. INTRODUCTION

## Purpose of Report

Although sometimes viewed as a temporary measure, the use of the septic system as a wastewater disposal method continues to be a viable alternative to centralized wastewater treatment facilities in areas with low density residential development. The decrease in federal funds available for construction of new treatment plants and the continued population growth in non-urban areas have renewed interest in decentralized wastewater management.

The growth trends in Massachusetts reflect the population boom in rural and semi-rural areas. As more people move to the country, the use of land marginally suited to subsurface waste disposal, coupled with the economic infeasibility of sewering many of these outlying areas, creates an increasing potential hazard to water quality and public health. As local communities have a responsibility to safeguard the health of their residents and the quality of their natural resources, they then have the responsibility to insure the proper performance of on-lot wastewater disposal systems. One means of fulfilling this responsibility is through the development of local performance standards for on-lot disposal systems in addition to traditional design and construction standards.

The most neglected aspect of septic system use is maintenance, and as such, it may be the single most important contributing factor to septic system failure today. Only by becoming involved in the inspection and routine maintenance of these systems can a community ensure their proper operation.

Such a septic system maintenance management program is proposed here. Examples of such plans from other areas of the country are outlined, and the needs in Massachusetts are discussed. The controlling parameters of septic system performance, and means by which that performance can be improved are also discused. A case study of the septic systems of Amherst, Massachusetts, is presented as a means of illustrating the practical aspects of performance analysis and the economic projections for a maintenance management program.

## Background

The Federal Water Pollution Control Act Amendments of 1972 (PL52-500) created effectively limitless resources for the centralized collection and treatment of sewage, as well as an atmosphere conducive to their widespread utilization. A schedule of strict discharge requirements placed an emphasis on the development of centralized treatment plant technologies, and the Construction Grants Program provided towns the means to implement those technologies. Though to a large extent successful in fulfilling its promise, PL92-500 also fostered a climate in which plant designers were reluctant to stray far from what was tried and true, and planners, as often as not, supported and prioritized projects according to expediency rather than efficacy (20).

However, events in the latter part of the 1970s and in the 1980s have forced a reevaluation of this approach. The last two U.S. Census Bureau reports indicate a continuing trend toward a new urban-rural balance. As more people move to the country and dispersed suburbia, it becomes increasingly more difficult to utilize a centralized treatment plan, both logistically and economically. Cost-effectiveness analyses in many areas have shown alternative treatment schemes and revitalization of existing facilities to be a better choice than installation of centralized collection systems. Also, although desirable and effective in many areas, sewering plans are now meeting considerable resistance from sectors of the rural public which perceive them as not only overly expensive, but as a precursor to undesired further development.

Other unforeseen problems associated with centralized treatment have also surfaced. Reduced groundwater recharge due to surface discharge of treated wastes has resulted in lower groundwater tables and, in some coastal areas, salt water intrusion. Centralized collection systems may also adversely affect local streamflows by exporting wastewaters to other river basins.

The momentum of small community wastewater management is now moving away from centralized facilities. More and more communities are now looking to "appropriate technology", i.e., small scale and low technology systems, to meet their wastewater disposal needs. In addition, the Clean Water Act Amendments of 1977 and 1987 have made available a larger portion of the federal money that does remain to projects utilizing "innovative and alternative" technologies and small flows systems. The Amendments have also made it incumbent upon project planners to give greater consideration to using lower cost or more environmentally sensitive wastewater systems. Though not met with as much enthusiasm as the 1972 amendments, these revisions have begun a slow change in the thinking of water pollution control officials. Step I Facility Plans for small communities must now exhibit a more comprehensive analysis of existing system conditions, possible repair or replacement of such systems, various configurations of alternative and conventional systems, and the relative cost-effectiveness of different schemes.

Prior to the 1977 amendments, on-site disposal systems were viewed as necessary but temporary solutions to the problem of wastewater disposal. They would do until the local population growth warranted sewering and central treatment. It is now clear that the population served by on-site systems has not diminished appreciably in the last 30 years, and it does not appear likely to do so in the future. Quite the contrary, there are many situations where on-lot disposal systems are the most appropriate wastewater management alternative available. On-site systems are a permanent and acceptable means of sewage treatment and disposal, and the standards which govern their design, installation, and operation must be reevaluated to ensure that they perform satisfactorily.

## 2. EXAMPLES OF ALTERNATIVE MANAGEMENT PLANS

Given the growth and continued existence of on-lot systems, the task at hand is to ensure that they work properly. That responsibility has traditionally fallen on the homeowner, with mixed results. Conscientious homeowners have maintained systems well and have taken care not to burden their systems with excessive or incompatible wastes. These homeowners are in the minority, however, and for the vast majority of on-site system users, disposal is "out of sight and out of mind." Maintenance is not considered until septic system problems infringe on their daily activities or lifestyle. Even then, cost considerations have often led to inadequate or substandard solutions to the problem. As a result, some areas served by septic systems have experienced significant water quality and public health problems.

Communities have a responsibility for their water quality and public sanitation and therefore have a responsibility for ensuring that proper on-lot wastewater disposal practices are followed. Recognizing this, communities have required permits for construction and repair of on-lot disposal systems. In some cases the construction or repair work must be inspected before a permit to use the system will be granted. Some communities have recognized a need for municipal regulation of performance as well, and have gone beyond requiring mere compliance with design and installation standards.

As one might expect, the responses to the need for better management of on-lot systems have been widely varied, with respect to both goals and means. They may be broadly categorized as either certification programs or as active management bodies. To illustrate the diverse and, in some cases, quite creative nature of some of the approaches, a number of examples of each from across the country follow. The management plans are summarized in Figure 1.

### Certification Programs

Several states have addressed the need for improved on-site system performance by taking measures to upgrade and standardize the procedures by which installation of such systems takes place. These approaches have taken the form of certification of officials involved in the site evaluation and construction process. Representative examples follow.

<u>Maine</u>: Prior to 1974, septic system site evaluation in Maine consisted solely of a percolation test modeled after U.S. Public Health Service Guidelines, and performed by plumbers, surveyors, or engineers. A high failure rate due to poor soils and/or improper installation prompted new

| | | ONSITE DISPOSAL | | | | |
|---|---|---|---|---|---|---|
| | | Auburn Lake Trails, CA | Stinson Beach, CA | Vermont Towns | Acton, MA | Fairfax County, VA |
| SERVICES OFFERED | Site Evaluation | ✓ | | ✓ | | ✓ |
| | Design Recommendation | ✓ | | ✓ | | ✓ |
| | Installation Inspection | ✓ | | ✓ | | ✓ |
| | Water Quality Monitoring | ✓ | ✓ | | | |
| | Operational Inspection | | ✓ | ✓ | ✓ | |
| | Repair by Management Body | ✓ | | | | |
| | Septage Disposal | | | | ✓ | |
| MANAGEMENT BODY | Municipality | | | | ✓ | |
| | Municipal Authority | | | | | |
| | Public Utility District | ✓ | | | | |
| | County Board of Health | | | | | ✓ |
| | Water District | | ✓ | | | |
| | Homeowners Association | | | | | |
| | Conservation District | | | ✓ | | |

Figure 1 Structure of Selected Management Programs

site evaluation regulations in the 1974 revision of the Maine Plumbing Code. Soil evaluation must now be conducted by registered professional engineers, certified geologists, or soil scientists by means of an observation hole rather than a percolation test. The regulations further require that towns hire a "certified" plumbing inspector to inspect system installation, with certification exams conducted by the state Division of Health Engineering. Finally, the counties of the state of Maine were divided into 11 districts, each with a state sanitarian on hand to supply technical assistance to local plumbing inspectors (31).

Wisconsin: Legislation was enacted in 1971 which required certification of all persons engaged in testing soils for the purpose of private domestic sewage disposal system installation. Because certification as a soil tester in Wisconsin was not restricted to any specific professions, the problem of limited education and experience needed to be addressed. A Soil Tester's Manual was developed by the Department of Health and Social Services. The Department also conducts training sessions, staffed by its own personnel, plumbing specialists, district engineers, general sanitarians, and soil scientists from the U.S Department of Agriculture Soil Conservation Service. Training includes both classroom and fieldwork, and subsequent satisfactory completion of a written examination is required for certification (14).

West Virginia: As of 1975, all septic tank installers must be certified by the State Health Department for such activity. Training classes for septic installers are conducted in conjunction with county health departments on a regional basis by State Health Department Regional Sanitarians, and certification is contingent upon passing a written examination (10).

Pennsylvania: By Pennsylvania state law, only certified officers retained by local agencies can issue permits for on-site sewage disposal systems. The primary qualification for certification is obtaining a passing score on a written examination which tests competency in each of four areas: 1) planning, 2) administration and enforcement, 3) technical aspects of soils, and 4) technical aspects of systems. The examination is prepared by the Department of Environmental Resources and administered by the State Board for Certification of Sewage Enforcement Officers. Since certification renewal is required every two years, continuing education courses are offered to keep officers abreast of innovations and program changes (18).

## Management Programs

Because the septic tank-leaching field system is a low-technology system which "runs by itself," it is often assumed that systems which are properly designed and installed will perform adequately for indefinite periods of time. While proper design and construction are essential to proper septic tank functioning, these alone are not sufficient. Septic tanks require periodic pumping to remove accumulated solids and periodic inspection to ensure the integrity and proper functioning of the system.

Post construction operation and maintenance has traditionally fallen entirely to the homeowner. Public agencies have not become involved except in cases of obvious failure, and then their role has been only to ensure proper reconstruction. Starting in the late 1960's however, some communities began to realize the importance of septic system management, especially where inadequate septic system performance threatened to lead to requirements that the on-lot systems be replaced by a centralized, sewered alternative. Some examples of state, regional, municipal, and private septic system management programs follow.

Vermont Rural Towns: Much of Vermont is characterized by ledges, steep slopes, and wet soils, and roughly 60% of its population is served by on-site systems. Many of the conventional standardized design and installation procedures either could not be implemented or simply did not work in this environment. The Vermont Association of Conservation Districts (VACD), working with the Cooperative Extension Service (CES) and the USDA Soil Conservation Service (SCS), created the post of District Sewage Specialist. Towns which sign working agreements with the District retain responsibility for promulgation of local health ordinances as well as the ultimate power of approval of applications for septic system construction permits. Homeowners file applications with the town, which then requests site and design evaluation by the District Specialist. The District Specialist, trained in soils and on-site sewage system design, makes use of SCS soil survey data rather than the conventional percolation test, which has proven to be extremely unreliable in Vermont. Within 48 hours, a report on site evaluation and design modification recommendations is sent to the town officials, who then make a decision on the application. The District Specialist also inspects and reports on system installation, and performs monitoring of all systems during the "non-installation" period of the year.

The District Specialist Program is politically acceptable because the Specialist functions only in an advisory capacity: local control and enforcement of regulations has been maintained. It has proven technically sound and provides timely and expert service to towns which could not otherwise afford permanent trained staff for such purposes. It is economical also in that one specialist may satisfactorily perform services for upwards of twenty towns. Furthermore, the Program draws on the administrative and technical resources of several already existing agencies.

Studies are currently underway to assess the feasibility of expanding the Specialist's duties to include maintenance of systems under the District's jurisdiction (29).

Auburn Lake Trails, California: Initial private development plans in 1969 for Auburn Lake Trails called for the installation of on-site septic tank systems for wastewater treatment and disposal. The California Water Resources Control Board (CWRCB) withheld approval of such systems, citing shallow soil depths, steep slopes, and a high water table, and recommended centralized treatment. The developer, leery of prohibitive costs for centralized treatment, produced data from his own feasibility study, and, in concert with the El Dorado County Health Department, argued that proper performance of on-site systems could be achieved through a management plan. The CWRCB then approved the development plan, contingent upon the total acceptance of all responsibility for the design, installation, maintenance and repair of on-site systems by the then existing Georgetown Divide Public Utility District (GDPUD).

As a result, in 1971 the GDPUD created the full-time post of wastewater program manager to develop and administer the program. Upon the request of a prospective homebuilder, the GDPUD conducts a rigorous site evaluation in several stages, encompassing study of all basic topographic and physical features, percolation tests, and detailed trench studies of soil profiles with the aid of the Soil Conservation Service. Armed with this comprehensive data, the District then makes design recommendations ranging from conventional on-site systems through alternative on-site systems, cluster systems, and offsite disposal, to outright condemnation. Further, the District provides preconstruction services and installation inspection, as well as semiannual monitoring of effluent status.

The fragile environment at Auburn Lake Trail dictates such comprehensive evaluation measures, but through the mutual efforts of the GDPUD, the developer's sanitation manager, and the County Health Department, a successful program has been developed in which all three share management responsibilities (25).

Stinson Beach, California: The Stinson Beach County Water District (SBCWD) has proven to be a viable on-site systems management body, but it may possess a greater historical significance for the impact it has had on state legislation and the perception of local management districts. Though a small community, numerous disposal studies had been conducted in the area since 1961. It was generally agreed that the existing on-site facilities posed a public health hazard--one survey had found a 22% overall average system failure rate in the community, with rates as high as 34% to 43% in some areas--but plan after plan to replace the on-site systems was rejected due to political resistance, economic costs, or environmental inadequacy. Finally, a workable plan emerged, based on an objective investigation of the environmental and engineering factors associated with alternative disposal methods initiated in 1975 by the SBCWD in conjunction with the California Water Resources Control Board (CWRCB). The plan was based on the belief that continued use of the existing facilities was most cost-effective, but acceptable performance could be attained only under the auspices of a governing management body with the adoption of a rigorous sampling, inspection, and monitoring program. Special legislation was required to make it possible under California law to form a management division within the SBCWD. Such legislation was passed in 1976.

Shortly therafter, the Onsite Wastewater Management District (OSWMD) was created within the SBCWD. The management program hinges upon an enforceable permitting scheme and a large scale water quality monitoring program. Seven surface water and six groundwater sampling stations were set up, with surface sampling conducted on a weekly basis and groundwater sampling done every two weeks. In addition, each existing system was inspected, resulting in the issuance of either a two year renewable Permit to Operate or a Failing System Citation. Each homeowner retains responsibility for maintenance, repair or replacement of his septic tank system. Failure on the part of the homeowner to correct the circumstances which precipitated issuance of a Citation may result in termination of water service, termination of occupancy, or contracting for necessary repairs at the owner's expense.

Guided by the experience with Stinson Beach, the California legislature adopted the "Onsite Wastewater Disposal Zone" Law (SB 430), which enabled public agencies which are empowered to manage sewer systems to create, under specified conditions, on-site wastewater disposal zones, and to bring their resources to bear on the proper operation and maintenance of systems in such zones. As a result, 14 of the 17 eligible public sewer management entities in California have been modified to properly manage on-site systems (1,21).

Acton, Massachusetts: There are no municipal wastewater collection facilities available to service the town of Acton's 20,000 residents. Virtually all of the town's residences, commercial establishments, and industrial facilities utilize subsurface disposal methods. Acton has experienced tremendous growth since 1950, with the population increasing by over 450% in the past 35 years. The rapid failure of several septic systems servicing multiple family apartment complexes, coupled with the knowledge that 85% of the town is underlain by soils classified by the

Soil Conservation Service as having severe limitations for the use of on-site disposal systems, led to the creation of the Sewage Study Committee in the early 1960's. The resulting proposed treatment facility was rejected by the town's Finance Committee, and debate over the issue continued for over ten years, as subsequent facilities plans were rejected by a populace concerned with preserving the residential character and rural atmosphere of the town.

Resisting state pressures to engage in 201 wastewater facilities planning, Acton, in 1975, opted to upgrade the current septage disposal facilities and concentrate on improved operation of existing on-site systems. Newly designed shallow septage treatment lagoons to be used in series with sand-drying beds were installed, and now function under the auspices of the town's Highway Department. It is currently the only municipally operated facility of its type in Massachusetts. Septage dumping privileges are contingent upon the septage hauler reporting complete records of the origin of the septage, amount pumped, the company doing the pumping, and whether the pumping was routine maintenance or problem related. Since the Acton Board of Health, under powers granted in the town's Sanitary Code, can order mandatory pumping of septic systems, these records have become a valuable tool in checking pumping frequency at a given location and alerting the Board to potential on-lot system problems. In addition, disposal problems at the apartment complexes were alleviated by the installation of privately owned and operated package treatment plants to service their needs.

Septage volume decreased by over 50% in the four years from 1976 to 1980. Most of that reduction reflects not only the replacement of the multiple-family subsurface systems, but also the high number of repairs to residential systems over the same time period. Groundwater monitoring at the septage disposal area initiated in 1977 reveals that the removal for most of the chemicals tested was better than 85%, and total and fecal coliform bacteria removal was 99.99%.

The success of the Acton septage management program is due primarily to the highly trained and knowledgeable staff at the Acton Board of Health and the Acton Engineering Department (2,28).

Fairfax County, Virginia: In response to a rising septic system failure rate in the early 1950's and the politically unpopular high capital expenses required for sewering outlying areas, the Fairfax County Environmental Health Department (EHD) began a comprehensive on-site disposal system regulatory program in 1954. Concentrating on rigorously regulating planning, design, and construction, the EHD decided that soil suitability would be the basis of a failure prevention program. The Virginia Polytechnic Institute soils extension service mapped all of Fairfax County for soils at 400 ft/in to serve as an information base for comprehensive studies carried out to correlate soils data with percolation tests. The EHD drafted legislation, subsequently enacted, to require a set of installation permits contingent upon meeting design and site criteria based on those studies.

The result is that system failure rates have dropped from 6-8% in the early 50's to less than 1% by the mid 60's. The emphasis of the program is on system design and installation. Although the EHD believes that a county operated operation and maintenance program would further improve performance, the current political atmosphere is not conducive to expanding local programs (4,35).

Lake Meade, Pennsylvania: In the early 1970's a rise in the area's septic system failure rate was accompanied by early signs of eutrophication in Lake Meade. Septage holding tanks were used as an emergency method of wastewater management, and when the local sewage treatment plant refused to accept any more of Lake Meade's septage, the Pennsylvania Department of Environmental Resources issued a moratorium on new construction in the community until the waste management problem was resolved. By resolution of Reading and Lattimore Townships in 1976, the Lake Meade Municipal Authority (LMMA) was legally empowered to provide wastewater disposal services for the community. Engineering studies resulted in selection of a plan that called for a low-pressure collection system utilizing individual grinder pumps and a small treatment plant.

Due to the community's low position on the state's wastewater facility Construction Grant priority list, alternative financing was sought. More than $1.5 million in grants and low interest loans were secured by the LMMA from the Farmer's Home Administration and the State Department of Commerce, contingent on the community's sharing a portion of the cost of construction of the sewage collection, transportation, and treatment system. The community's share was arranged by the LMMA's bond counsel with a local bank.

The process of developing the institutional framework and developing the powers of the LMMA was carried out primarily through the active involvement of the Lake Meade Property Owner's Association (35).

Otter Tail County, Minnesota: With the adoption of the Shoreline Management Ordinance in 1971, Otter Tail County became the first county in the state of Minnesota to establish and adopt an administrative and regulatory program governing the use of on-site disposal systems in lake-front communities. The management program was established to provide a comprehensive review of septic system performance in sensitive lake-front areas and to establish a regulatory framework for upgrading and rehabilitating failing facilities.

To comply with the County's Shoreline Management Ordinance, the Rothsay Camp Property Owners Association constructed a small community cluster wastewater system. The only legal agreement signed by the members was a Deed of Easement to permit construction, operation, and maintenance of a system that would cross each member's property. Property transfer is contingent upon the new owner's compliance with the easement requirements. Consisting of individual septic tanks discharging to a common subsurface field a suitable distance from the lake, the system is less expensive and easier to monitor and maintain than individual septic systems.

The development of the program was greatly facilitated by the County Department of Land and Resource Development, which provided an effective liaison between state agencies, county officials, and local residents. The Rothsay Camp Association's management plan is typical of the cooperative and voluntary approach to wastewater disposal problems utilized throughout much of the state of Minnesota (35).

## Regulations in Massachusetts

Minimum requirements for the subsurface disposal of sewage in Massachusetts are outlined in the Massachusetts Environmental Code, Title 5, 310 CMR 15. These regulations are based almost exclusively on design and installation compliance standards. All plans for subsurface disposal systems must be prepared by a Professional Engineer or other legally authorized professional and submitted to the local Board of Health as part of a disposal works construction permit application. These plans must include design calculations, test data, and location of any nearby streams, wetlands, or water supply sources. Approval is based strictly on design criteria outlined in Title 5. The Board of Health or the state Department of Environmental Quality Engineering may inspect the site during installation and modifications may be required at the discretion of these agencies. After installation, maintenance and operation are entirely the owner's responsibility. The Board of Health is not involved in system operation unless a system creates objectionable conditions or proves to be a source of pollution to any of the waters of the Commonwealth. At such time the Board may order repair or pumping. Failure to comply may result in the Board contracting the necessary work at the owner's expense.

## 3. CAUSES OF SEPTIC SYSTEM FAILURE

Before discussing the applicability of any septic system management plan for Massachusetts, the problem may be more clearly defined by a closer look at the processes governing septic system failure. Proper choice of the most effective means of alleviating failure related problems would be made easier if the dominant factor influencing the failure process could be isolated. To a certain extent this seems possible.

The most commonly held definition of septic system failure entails either the surfacing of raw effluents or the subsurface ponding of water in the seepage bed resulting in sluggishness or stoppage of flow through the system (12).

Though in some cases failure may be brought on by the deterioration of the installed system (pipe collapse, septic tank cracking, corrosion of metal fittings), the vast majority of failures are associated with problems in the disposal medium (i.e., the soil) (7). The single most important failure mechanism is the formation of an impermeable clogged or crusted layer at or near the disposal bed-soil mantle interface. This reduction of permeability is an apparently inevitable though not immutable function of subsurface waste disposal. Clogging results from three interdependent processes: growth of a microbially induced slime layer, physical entrapment of suspended solids from the septic tank effluent, and reduction of sulfate to an impermeable ferrous sulfide due to development of anaerobic conditions in the slime layer (21).

Factors influencing the speed with which these processes occur are varied and include natural physical characteristics such as high groundwater, topography, soil type, and depth to bedrock, as well as problems incurred through design and use such as undersizing, overloading, improper bed construction, septage pumping schedules, and dosing patterns. Efforts to directly link the occurrence of failure to the above factors have produced an array of studies, and although it can be argued that none may lay claim to definitive responsibility, it does appear as though a generalized cause and effect relationship may be inferred.

Most states, Massachusetts among them, rely on soil percolation rates and depth to groundwater or bedrock to assess septic system site suitability. When soil types are also taken into account, significant improvements in performance have been reported. A comprehensive study of septic system survival data in Fairfax County, Virginia indicated that incorporation of soils data into the siting procedure may have as much as doubled the life expectancy of septic systems compared with the national average, which is generally reported as being 15-25 years (4). The Connecticut Agricultural Experiment Station, in a study of the longevity of septic systems in Connecticut soils, reports significant correlations between soil type and failure rate, but it also points out anomalies illustrating the importance of other factors, such as construction technique and weather at the time of installation (13). Both laboratory and field studies exist which imply that clogging and failure may be independent of soil composition and texture (6,12). However, most failures which appear to be independent of soil type seem to find their basis in operation and maintenance. Effluent overloading has been shown to have a dramatic effect on system longevity, and Popkin and Bendixen suggest that intermittent dosing of the leaching field may increase system life expectancy by as much as 100 to 300% (24).

In sections of Marin County, California, in the mid 1960's, where septic systems were failing at a rate of 30%, a survey of septic tank pumping periodicity was conducted. The study revealed that the average period between pumpings was 60 years, or more realistically, that the majority of the septic tanks in the county had never been pumped. Studies done on solids accumulation in septic tanks have shown that as sludge accumulates, an equilibrium condition is approached in which the clear space between the settled sludge layer and the floating scum layer remains constant. Beyond this point effluent clarification ceases and solids apparently pass right through the tank to the leaching field (5). This clearly points out the need for regular periodic pumping to maintain an optimum effluent detention time in order to insure adequate settling of suspended solids.

Mancl related recommended pumping frequency to family size (a surrogate for solids loading) and tank size. Her recommendations are presented in Table 1 (17).

What these studies show is that careful attention to the physical attributes of the disposal medium will likely lead to a long and productive septic system lifespan. Where failure does occur, its cause can often be traced to improper operation and maintenance.

This is not entirely surprising, as virtually all aspects of siting, design, and construction are generally fairly well regulated. Once installed, proper operation is the user's responsibility, and experience has shown that effective upkeep cannot be insured through exhortation alone. It follows then that, to be most effective, management efforts should be centered on improving the maintenance of septic systems after installation.

TABLE 1

Estimated Septic Tank Pumping Frequency

(in years)
(from Mancl (17))

| Tank, in gallons (1) | Number of Persons in Residence 1 (2) | 2 (3) | 3 (4) | 4 (5) | 5 (6) | 6 (7) | 7 (8) | 8 (9) | 9 (10) | 10 (11) | Tank, in cubic meters (12) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 5.8 | 2.6 | 1.5 | 1.0 | 0.7 | 0.4 | 0.3 | 0.2 | 0.1 | — | 1.9 |
| 750 | 9.1 | 4.2 | 2.6 | 1.8 | 1.3 | 1.0 | 0.7 | 0.6 | 0.4 | 0.3 | 2.8 |
| 900 | 11.0 | 5.2 | 3.3 | 2.3 | 1.7 | 1.3 | 1.0 | 0.8 | 0.7 | 0.5 | 3.4 |
| 1,000 | 12.4 | 5.9 | 3.7 | 2.6 | 2.0 | 1.5 | 1.2 | 1.0 | 0.8 | 0.7 | 3.8 |
| 1,250 | 15.6 | 7.5 | 4.8 | 3.4 | 2.6 | 2.0 | 1.7 | 1.4 | 1.2 | 1.0 | 4.7 |
| 1,500 | 18.9 | 9.1 | 5.9 | 4.2 | 3.3 | 2.6 | 2.1 | 1.8 | 1.5 | 1.3 | 5.7 |
| 1,750 | 22.1 | 10.7 | 6.9 | 5.0 | 3.9 | 3.1 | 2.6 | 2.2 | 1.9 | 1.6 | 6.6 |
| 2,000 | 25.4 | 12.4 | 8.0 | 5.9 | 4.5 | 3.7 | 3.1 | 2.6 | 2.2 | 2.0 | 7.6 |
| 2,250 | 28.6 | 14.0 | 9.1 | 6.7 | 5.2 | 4.2 | 3.5 | 3.0 | 2.6 | 2.3 | 8.5 |
| 2,500 | 31.9 | 15.6 | 10.2 | 7.5 | 5.9 | 4.8 | 4.0 | 4.0 | 3.0 | 2.6 | 9.5 |

[a]More frequent pumping is needed if garbage disposal is used.

## 4. NEEDS IN MASSACHUSETTS

According to the 1970 census, nearly 500,000 housing units in Massachusetts, or 27% of all units, rely on on-site waste disposal systems. The septic tank soil-absorption system is by far the most common means of subsurface disposal, comprising 98% of all such systems (33).

A review of available published 208 Regional Planning Reports (27) reveals an interesting relationship between population growth, population density, and septic system distribution (Figure 2). Five of the eight regions which recorded such figures reported that the percentage of their population served by sewers was 50% or less. Four of those five expected to experience growth rates in excess of 18% during the 20 years following the 1975 state census. With the exception of Cape Cod in the summer time, all have population densities of less than 640 people per square mile, or less than one person per acre. This figure is well below population densities commonly assumed acceptable for efficient subsurface disposal. Two of the remaining three planning studies reported projected growth rates of 11% or less. The Berkshire County Regional Planning Commission projects only 5% growth and is 84% sewered. The Metropolitan Area Planning Council projects only 11% growth in a densely populated area, and although no total sewering figures are available, reports on the nine river basins within this region do reveal a trend. The three inner core basins of the Mystic, Lower Charles, and Neponset Rivers which house the majority of the metropolitan area's population, project negligible growth, and are nearly entirely sewered. Four watersheds (Weymouth, Ipswich, Sudbury-Assabet-Concord, and North-South) list a cumulative sewering of less than 50% and projected a growth rate of over 30%. Sewering data was not available for the Upper Charles and North Coastal basins (27).

The results of these 208 Areawide Planning studies have implications which warrant consideration for planning in Massachusetts in general. It appears that the population is expanding most rapidly in areas which rely heavily on on-site disposal. Some of this growth will claim the available expansion capacity of sewage treatment plants in these areas. Some of it will undoubtedly occur in areas too sparsely populated to have had plants built, and some too far away from existing plants to be economically sewered. With fewer federal subsidies available for construction of wastewater treatment plants and sewers in these areas the cost of providing centralized treatment may be prohibitive. This being the case, there is, and will continue to be, a great many towns in Massachusetts which rely very heavily on on-lot disposal systems to meet their wastewater disposal needs.

| | 1975 POPULATION (1000's of people) | PROJECTED GROWTH TO 1995 (1000's of people) | AREA ($mi^2$) | POPULATION DENSITY ($\frac{people}{mi^2}$) | % SEWERED |
|---|---|---|---|---|---|
| SOUTHEASTERN REGIONAL PLANNING COMMISSION | 560 | 18% | 894 | 626 | 50% |
| MONTACHUSETTS REGIONAL PLANNING COMMISSION | 143 | 20% | 347 | 412 | 50% |
| CAPE COD PLANNING & ECON. DEVELOPMENT COMM. | 128 winter<br>382 summer | 48%<br>49% | 440 | 291<br>868 | 25% |
| MARTHA'S VINEYARD COMM. | 29 w<br>45 s | 62%<br>56% | 97 | 81<br>464 | 10% |
| CENTRAL MASS. REGIONAL PLANNING COMMISSION | 398 | 8% | 627 | 635 | 50% |
| OLD COLONY PLANNING COMMISSION | 194 | 22% | 172 | 1128 | N/A |
| BERKSHIRE COUNTY REG. PLANNING COMMISSION | 105 | 5% | 262 | 401 | 84% |
| METROPOLITAN AREA PLANNING COUNCIL | 2900 | 11% | 1260 | 2300 | N/A |
| METRO AREA SUB-BASINS: Mystic, Lower Charles, Neponset | 64% of total Met. Pop. | Stable | - | - | 100% |
| METRO AREA SUB-BASINS: Weymouth, Ipswich, SuAsCo, North & South | 20% of total Met. Pop. | 30% | - | - | 50% |
| METRO AREA SUB-BASINS: Upper Charles, North Coastal | 16% of total Met.Pop. | 12% | - | - | N/A |

Figure 2 Population and Sewering Data from Available 208 Plans

While the sparse population densities of many areas experiencing rapid growth preclude centralized wastewater treatment, it is fortunate that at the same time they do provide a population distribution which is conducive to subsurface disposal. However, greater care must be taken in the siting and operation of such systems as more marginally suited land is used for this purpose. Title 5 requires that at least 4 feet of pervious soil must exist below the bottom of a leach field. In an extensive study to assess the septic disposal suitability of Massachusetts soils, Veneman (33) found about 45% of the soils to be underlain by hardpan within 3 feet. Furthermore, a large proportion of Massachusetts soils have seasonally high groundwater tables, rendering them unsuitable for septic effluent disposal. Veneman concludes, however, that when proper design and construction procedures are followed, the minimum leaching area requirements established in Title 5 are more than adequate to protect the environment from septic tank pollution. The key then will be strict adherence to siting requirements.

As was illustrated in Chapter 2, knowledgeable management of on-site disposal systems can overcome a number of disposal medium limitations. This is seen particularly well in Acton, Massachusetts, where in an area largely underlain by soils deemed unsuitable for septic disposal, an annual failure rate of less than 5% has been experienced. This success may be primarily attributed to a stringent local Sanitary Code strictly enforced by knowledgeable officials.

Development of any septic management scheme in Massachusetts must take into account the state's long history of strong home rule. None of the 208 plans reviewed recommended the creation of a new management agency, and most of them recommended retention of local control over water quality issues. Regional or intermunicipal options were most carefully considered in areas where such agencies were already quite active, such as the densely populated Boston metropolitan area. For this reason, the alternative management schemes from other states previously reviewed may yield only a few viable examples of solutions applicable to problems in Massachusetts, but useful information may be gleaned from several others.

Participation in on-site waste management on a state-wide or even a regional level, if it exists at all, would seem to be limited to certification programs. These programs have been quite useful in other states. Primarily they foster only greater compliance with existing regulations, which is valuable, but offer no assistance in the area of improved operation and maintenance.

Local, intermunicipal, and county Boards of Health offer the most promising potential for septic system management in Massachusetts. They are most familiar with the extent and nuances of the local problems; they already hold the necessary records; and users are quite familiar with their role in septic system waste disposal. To a lesser extent, homeowners' or lake associations may also provide acceptable management bodies.

Of particular interest to this study is the extent to which various wastewater treatment options were presumed applicable within a 208 region. The two most frequently considered wastewater treatment options in the greatest proportion of towns in each region were septic tank inspection and maintenance and septage disposal. A study of 208 Plans in Massachusetts revealed that frequent consideration of an option is a measure of the planners' belief in the technical and political feasibility of implementation of that option (27). If this is the case, septic system maintenance management plans may prove to be not only the most useful and effective method of pollution abatement available, but also the most likely to succeed in those areas of Massachusetts which rely heavily on septic system disposal.

## 5. COMPONENTS OF A SEPTIC SYSTEM MANAGEMENT PLAN

To assure the continued successful operation of the septic system as a viable waste disposal process, proper management of all aspects of construction and use is required. One poorly executed step may effectively negate all the time, energy, and resources spent on the remaining aspects of the process. For this reason, each of the following activities must be carefully considered:

- Site Evaluation
- System Design
- Installation Inspection
- Operational Inspection
- Scheduled Pumping
- System Repair and Rehabilitation.

A brief discussion of some of the important aspects of each follows.

Site Evaluation: The interpretive value of data received from the percolation test, long the primary site evaluation tool for most states, is currently being viewed with increasing skepticism. Several states, such as Vermont and Virginia, have discouraged sole reliance on percolation test results for site assessment. However, while other site conditions may warrant careful study, particularly in marginally suitable land, the perc test remains a valuable indicator of one of the most important septic system performance parameters.

In addition to the perc test, soils information such as that compiled by the Soil Conservation Service can be very important in site evaluation. Valuable use has been made of information on soil type, soil texture, soil structure, and soil profile, as well as natural drainage, bedding plane, and bedrock slope. Sources of such information include the U.S. Soil Conservation Service, the Cooperative Extension Service, floodplain management records, and possibly, water-well logs. Other direct, on-site methods of study, such as borings, observation pits, and trenches, are used as a matter of course in many states.

The presence on the permitting board of people either trained in soil science or well-versed in the performance history of a given area may preclude the necessity of much inter-agency communication. However, all such permitting boards should be aware of the need for analysis of this type of data, and have at their disposal the means to obtain it.

System Design: Once the proper site evaluation data is collected, the pertinent design parameters must be reviewed for each site. The design criteria should include consideration of soil permeability, depth to impervious layer, seasonal groundwater fluctuations, structural limitations (driveways, outbuildings, etc.), the anticipated loading rate, and reserve space for field expansion. Special circumstances may warrant an alternating dosing pattern (e.g., using two leaching fields and periodically resting one or the other) or a unique trench configuration. As the number of requests for construction on more marginal land increases, design review by a person with training in subsurface disposal system design will be increasingly necessary. In Massachusetts, the design criteria set forth in Title 5 have thus far proven to be generally adequate.

Installation Inspection: Frequently, modifications to the desired design must be made in the field during construction. If these changes are improper (either in design or construction), there may be no simple means to correct the damage or inadequacies after construction. For this reason, it is imperative that contractors either be quite familiar with the relative significance of all design criteria, or they must be required to clear each change with the designer or the local permitting board. Clearly the former is more economical, and a training and certification program for contractors could aid greatly in avoiding costly delays. "As-built" plans should be required, and should be reviewed prior to system burial. Additionally, there should be at least one on-site installation inspection performed by a septic system specialist. Key elements to check are pipe joint seals, septic tank integrity (esp. for leakage), slope of drainage bed, and in particular, that smearing or compaction of the disposal bed sidewalls and bottom has not occurred during construction. Where smearing occurs, walls should be scarified so that effluent infiltration into the final disposal medium is not impeded. This last measure is especially important if construction is carried out in wet weather. More than one inspection visit to a site may be required, particularly if design modifications are made. The exact number of visits will vary with the intricacy of the design, complexity of the site, and the competence of the contractor (25).

Operational Inspection: Once in operation, a septic system is most often forgotten by the homeowner unless the system seriously malfunctions - a situation which usually results in the backup of wastewater in the household plumbing or in the breakthrough of effluent to the soil surface above the leaching field. To catch and correct small problems before they lead to costly repairs, a biennial inspection schedule should be maintained. Inspection services include determination of sludge and scum volume in the septic tank, an odor investigation, and a disposal field examination for surfacing of effluent, or near-surfacing as evidenced by changes in the vegetation pattern. Soil cores may be of use in determining the extent to which the soil has been degraded as a disposal medium. The requirement of the installation of capped risers on septic tanks by the GDPUD in California has greatly facilitated the inspection of scum and sludge levels. Experiments using aerial photography with analysis to reveal effluent influenced vegetation patterns has proven successful in a number of study sites, including Holliston, Massachusetts (9). Where problems are suspected, or where the receiving surface or ground waters are especially sensitive to pollution, surface and ground water quality monitoring should be required (see Stinson Beach description in Section 2). In lake-front areas, dye tests, bacteriological testing, and aquatic vegetation observations may prove useful in determining the likely presence of effluent plumes (15).

An inspector should also record any additions to the house or changes in the number of residents. A check of the age of the system and the maintenance history may prove useful in seeking out potential problems.

Pumping: Perhaps the single most important, yet largely neglected, aspect of septic system management is that of system pumping. For example, a 1976 survey found that 55% of the homeowners in three Colorado communities performed no maintenance on their on-site systems unless the system failed and directly affected their lifestyle by backing up into their house (8). That study and the study revealing a 60-year septic tank pumping periodicity in Marin County bear figures which are representative of other surveys.

Unfortunately, failure to pump tanks regularly may be one of the most important contributing factors to system failure. By overloading a septic tank's settling function, a far richer effluent is passed on to the disposal medium. This results in more rapid clogging and, eventually, a shorter system lifespan. The U.S. EPA recommends pumping every three to five years (32). A more detailed evaluation of pumping frequency was prepared by Mancl and was included earlier as Table 1 (17). Although the exact figure will vary with loading rates, system design, and soil characteristics, a regular pumping schedule is critical to the success of any septic system management plan.

Repair and Rehabilitation: Given that failure of a septic system creates both a public health hazard and a water quality problem, it is within the public purview to regulate the maintenance of such systems in order to insure proper operation. Given also the fact that under private maintenance, rehabilitation of poorly functioning systems often does not occur until operation ceases altogether, a strong case can be made that needed repair and rehabilitation should be a function of a total management scheme. Where a management body assumes responsibility for regulating all other significant aspects of septic system use, correcting faulty systems is the final step in the process.

There are three main advantages inherent in the assumption of repair and rehabilitation responsibilities by a management body. The first, mentioned above, is that timely repairs significantly reduce the potential for water quality and public health hazards. The second is that regular maintenance may preclude more costly reconstruction at a later date by extending the life of the system and minimizing premature failures. The third is that most systems do inevitably fail. When they do, unexpectedly large rehabilitation costs can prove to be extremely burdensome to the homeowner. By incorporating future repair costs into an annual user charge and distributing those costs over all users, the burden of large unexpected reconstruction costs to homeowners could be eliminated.

Details of Repair and Rehabilitation: One major advantage of a septic system is that is has no moving parts. What structural damage that does occur results from settling, carelessness in pumping or inspection, and corrosion of metal parts. Repair work associated with such damage usually entails correcting cracked baffles or leaky inlet or outlet joints. Barring a cracked tank, repairs of a structural nature should not be extensive or frequent, and as such are often considered minor. However, records of costs and frequency of repairs of this nature are inadequate to make a definitive statement about their extent. With proper management of repairs, these records would be kept and a proper assessment of their impact could be made.

Of greater consequence are circumstances requiring repair of the disposal medium. At times a sluggish leach field may be rehabilitated by the introduction to the field of a reagent to oxidize the clogging materials. Hydrogen peroxide has been used with some success in some areas to restore permeability before complete failure occurs. However, peroxide treatments have also resulted in reduced soil conductivity (i.e., further clogging) in other areas. Therefore, such treatments can not be recommended without further research. In general, researchers have concluded that commercial products which purport to clean or rehabilitate septic systems are ineffective, and in some cases pose significant potential for groundwater contamination (19).

Once flow ceases entirely, major repair is required. These repairs usually involve either new trench extensions or excavation and rehabilitation of the original site. This is the type of failure which is of greatest concern to both homeowners and health officials, and several studies on the frequency of system failures appear in the literature. The most commonly quoted figure in longevity studies is that 50% of all systems attain the age of 25 years, referred to as the system half-life (21). Longevity studies in the states of Washington and Arizona, and in Fairfax County, Virginia, found that standard systems function from 25 to 30 years, and even longer with proper maintenance (23). A study of longevity of septic systems in Connecticut calculated half-lives ranging from 23 to 38 years, depending on the soil, with a mean of 27 years (13). Still another collection of survival data from 12 sites across the country estimated half-lives ranging from 5 to 17 years, with most figures falling below 10 years (5). The wide range in values for half-life certainly reflects variations in design, siting, and construction techniques, but may also reflect biases in data interpretation or simply an inadequate body of data. As was stated above, a half-life of approximately 25 years appears most often in longevity studies, and has gained general acceptance. Clearly, however, this can only be an initial estimate for any given area. Site-specific data must be collected to confirm or recalculate the half-life for local conditions.

Septic system failures are often reported as a percentage failure rate per year of the total number of systems in operation. Unless the installation rate has been uniform over a long period, this information is of little predictive value, and should be used with caution in areas which have experienced non-uniform growth. Of far greater importance is the age distribution of the operational systems. Septic systems in any given area frequently exhibit a unique pattern of failure which can best be described by a survival curve, in which the survival percentage of the total number of systems is given as a function of the age attained at time of failure. If the age distribution of operational systems and the history of past failures is known, the survival curve can be used to estimate the likelihood of future failures.

The method of construction of a survival curve is treated more fully in the following section and in the Appendix.

# 6. AMHERST CASE STUDY

To demonstrate the failure analysis methodology and the economics of septic system maintenance management, a case study using data from the town of Amherst, Massachusetts, is presented.

Amherst, Massachusetts, located in the Connecticut River Valley in central Massachusetts, has a population of approximately 25,000 fulltime residents, expanding to 35,500 when the local colleges and the University of Massachusetts are in session. The Amherst sewer system currently services approximately 93% of the town's residences, including much of the most densely populated areas. The remaining housing units are served by on-site disposal systems, primarily septic tank-soil absorption systems. However, many of these are located in relatively densely populated areas and performance problems may pose hazards to the ground and surface drinking water supplies (particularly the Lawrence Swamp aquifer, the town's major water supply source).

A study is currently underway to assess the feasibility of enlarging the sewer system. The desire to strengthen environmental protection via expanded sewer service is offset, however, by the likelihood that sewering will result in even greater development pressure in sensitive areas. Since the early 1960s, the town has been growing quite rapidly due in large part to the burgeoning academic community associated with the University of Massachusetts. Pressure to limit growth resulted in a sewer connection ban in the early 1970's. More recently the town voted a two year moratorium on residential construction in 1986.

## Available Data

Efforts to evaluate the performance of on-site systems in Amherst have been facilitated by the excellent records kept by the town's Board of Health. Consistent and comprehensive records of septic system construction and repair permits for the past 13 years are available. It should be noted here that repair permits are needed only for those systems requiring major reconstruction. Therefore records do not exist for minor repairs such as broken baffles, faulty distribution boxes, etc. Information was obtained from these files on the number of new systems installed and the number and types of failures for each year of the study period.

By the end of 1985 there were 494 septic systems operating in Amherst (3). For the period 1974-1985 there were 51 recorded failures which entailed major repair of the disposal bed or septic tank, or both. Records at the wastewater treatment plant, where septage pumped from septic tanks in Amherst and three neighboring towns is treated, indicate that approximately 230 loads of septage from Amherst are treated per year (FY'83-FY'87 average). The average septage load treated was slightly over 1000 gallons (1066 gal). Thus the septage disposal represents the pumping of approximately 230 systems per year. To compute the exact number pumped would require information on the sizes of the individual tanks pumped. All systems installed since 1978 have at least 1000 gallon septic tanks; older systems most likely have smaller volumes. Thus the average septic system in Amherst is being pumped approximately once every 2.15 years (494 systems/approx. 230 pumped every year). Inspection of the records reveals that some systems are pumped very frequently; therefore others must be pumped at much greater intervals.

A telephone survey of owners of all 51 systems which had failed during the study period was conducted as part of this research to determine the age of the system at the time of failure and the costs of the repairs. Data on failed systems for which such information was unavailable at the time of the survey was obtained through interviews with local town officials and contractors. Age at failure was known with certainty for 72% of the failed systems. Original system installation for the remaining failures was assumed to have occurred at the date of the house construction. For the few very old houses, a default value of 50 years was assigned as a maximum age at system failure.

## Installation and Failure History

Information on installations and failures prior to 1974 is unavailable. Therefore two assumptions concerning these data have been made in this research. The first assumption is that the septic system installation rate roughly parallels the Town's growth rate through time. The second is that construction and operation practices have not changed significantly over the past 30 years, and so past failures may be adequately inferred through study of more recent records. (This is not strictly correct, but the data in the Appendix indicate that more than half of the systems have been built since 1974 and over 87% have been constructed since 1962.)

To estimate past installation rates, population curves were constructed using data from the U.S. Census Bureau and the Massachusetts State Census Bureau (see Figure 3). The gap between the fulltime and

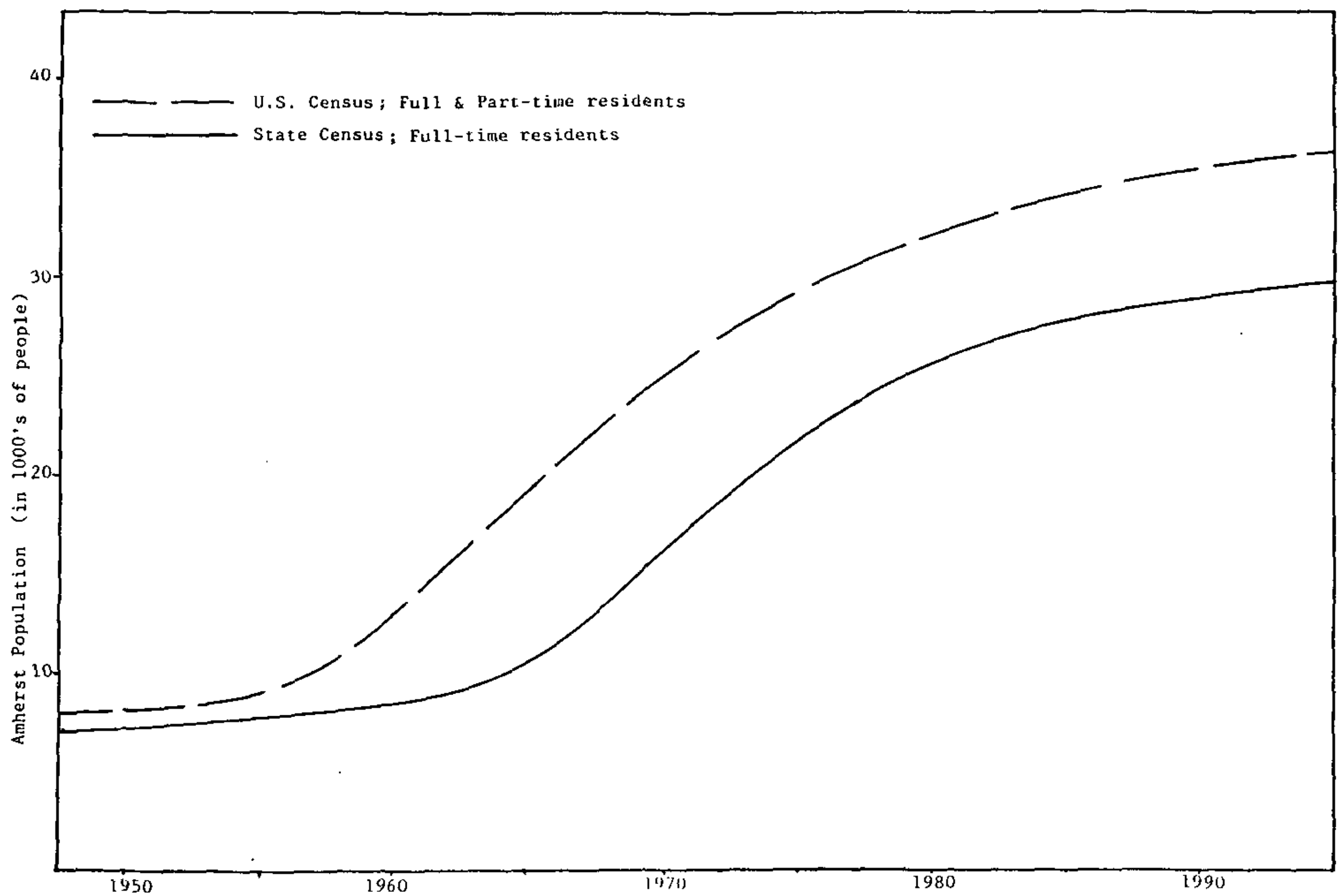



Figure 3 Population Growth Curves for Amherst

the seasonal populations began to widen considerably in the 1960s due largely to the growth of the University of Massachusetts student population.

To re-create a septic system installation pattern from this growth curve, it was assumed that although the growth occurred most rapidly from 1965 to 1975, most of this growth occurred in areas already served by sewers (e.g., apartment complex and subdivision construction), and the septic system installation rate would not have been as steep as the population growth curve. Since the exact nature of this relationship is not known, a constant installation rate was assumed for the period 1965-1985. Known installation values were plotted (see Figure 4); the best-fit line yielded an average rate of 17 systems installed per year. Over the same period, the population increased at a rate of 880 people per year. On average, therefore, there was one new system installed for every 52 new Amherst residents each year. This rate was then applied to the remainder of the curve to determine past installation rates and to predict future rates, as shown in Figure 4.

## Septic System Survival Curve

The survival curve for Amherst septic systems was generated using the assumption that the pattern of failure for septic tanks which were both installed and had failed within the past 12 years applies to the pattern for the preceeding 12 years as well. This seems a reasonable assumption since the computed failure rates for each year (see Appendix) do not vary significantly over the first 12 years. With this assumption, inferred and real data for the past 24 years were used to construct the survival curve in Figure 5. (See the Appendix for the data and the method of construction.)

A computer program was written which simulated the performance described by Amherst's septic system survival curve, and the historical installation sequence described earlier was run through it to determine the failure history and the current age distribution. (The program is listed in the Appendix.) The results are listed in Table 2. They provide the data on which the future failure predictions are based.

## Economics of a Septic System Maintenance Program

As was mentioned earlier, repair permits are issued in Amherst only for those jobs requiring field or tank reconstruction. For this reason records do not exist for frequency or cost of repairs on items such as baffles or joints. It should be noted here that due to this lack of data, predictions of such repairs are not included in the final economic cost model. One study of over 2800 septic systems in Connecticut for which such data are available reports that only 10% of

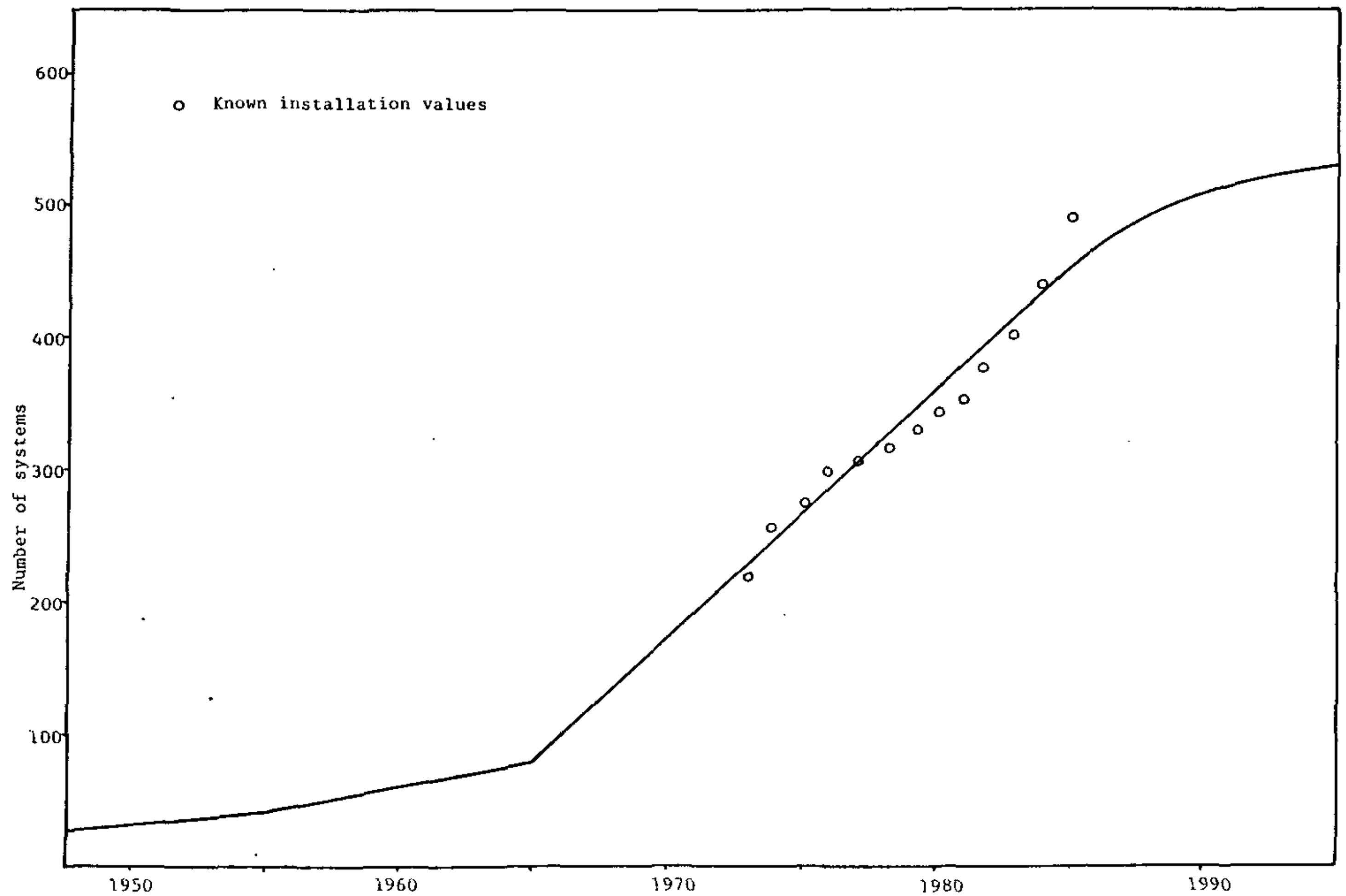



Figure 4 Septic System Installation Rate for Amherst

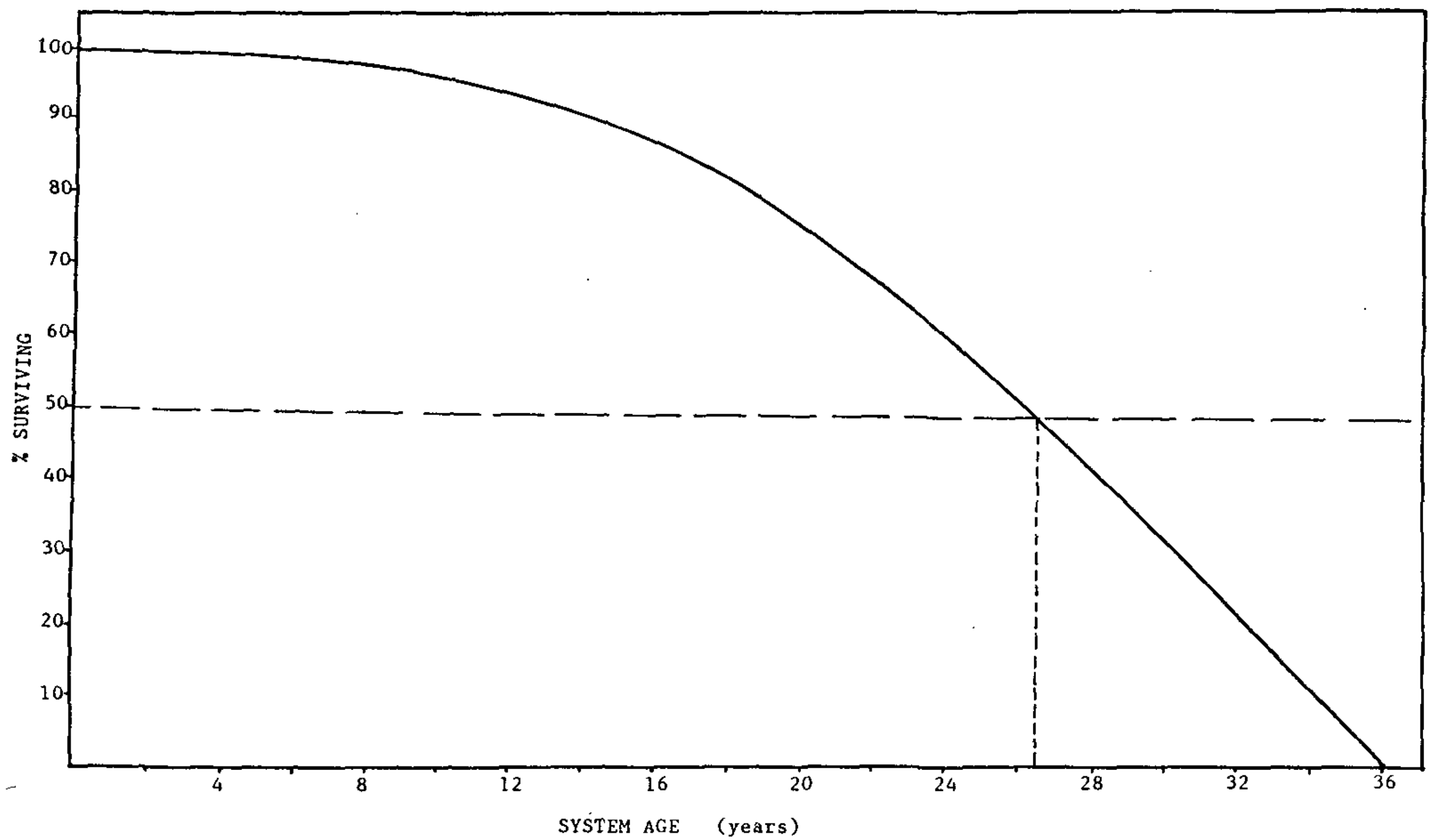



Figure 5 Septic System Survival Curve for Amherst

## TABLE 2

### Septic System Age Distribution for Amherst

| AGE | NUMBER STILL WORKING | NUMBER INSTALLED | CUMULATIVE TOTAL | NUMBER OF FAILURES | % SURVIVING |
|---|---|---|---|---|---|
| 1 | 45 | 46 | 508 | 1 | 99.80 |
| 2 | 37 | 37 | 462 | 0 | 99.80 |
| 3 | 23 | 24 | 425 | 1 | 99.57 |
| 4 | 16 | 17 | 401 | 1 | 99.32 |
| 5 | 15 | 16 | 384 | 1 | 99.06 |
| 6 | 17 | 18 | 368 | 1 | 98.79 |
| 7 | 12 | 13 | 350 | 1 | 98.51 |
| 8 | 11 | 12 | 337 | 1 | 98.22 |
| 9 | 28 | 30 | 325 | 2 | 97.61 |
| 10 | 22 | 24 | 295 | 2 | 96.95 |
| 11 | 40 | 42 | 271 | 2 | 96.24 |
| 12 | 17 | 20 | 229 | 3 | 94.98 |
| 13 | 17 | 20 | 209 | 3 | 93.61 |
| 14 | 17 | 20 | 189 | 3 | 92.13 |
| 15 | 14 | 17 | 169 | 3 | 90.49 |
| 16 | 18 | 21 | 152 | 3 | 88.70 |
| 17 | 16 | 20 | 131 | 4 | 86.00 |
| 18 | 14 | 17 | 111 | 3 | 83.67 |
| 19 | 10 | 13 | 94 | 3 | 81.00 |
| 20 | 7 | 11 | 81 | 4 | 77.00 |
| 21 | 7 | 11 | 70 | 4 | 72.60 |
| 22 | 6 | 10 | 59 | 4 | 67.68 |
| 23 | 6 | 9 | 49 | 3 | 63.54 |
| 24 | 1 | 4 | 40 | 3 | 58.77 |
| 25 | 4 | 7 | 36 | 3 | 53.87 |
| 26 | 1 | 4 | 29 | 3 | 48.30 |
| 27 | 2 | 5 | 25 | 3 | 42.50 |
| 28 | 0 | 3 | 20 | 3 | 36.13 |
| 29 | 0 | 3 | 17 | 3 | 29.75 |
| 30 | 2 | 4 | 14 | 2 | 25.50 |
| 31 | 1 | 3 | 10 | 2 | 20.40 |
| 32 | 0 | 1 | 7 | 1 | 17.49 |
| 33 | 1 | 2 | 6 | 1 | 14.57 |
| 34 | 0 | 1 | 4 | 1 | 10.93 |
| 35 | 0 | 1 | 3 | 1 | 7.29 |
| 36 | 0 | 1 | 2 | 1 | 3.64 |
| 37 | 0 | 0 | 1 | 0 | 3.64 |
| 38 | 0 | 0 | 1 | 0 | 3.64 |
| 39 | 0 | 0 | 1 | 0 | 3.64 |
| 40 | 0 | 0 | 1 | 0 | 3.64 |
| 41 | 0 | 0 | 1 | 0 | 3.64 |
| 42 | 0 | 0 | 1 | 0 | 3.64 |
| 43 | 0 | 0 | 1 | 0 | 3.64 |
| 44 | 0 | 1 | 1 | 1 | 0.00 |
| 45 | 0 | 0 | 0 | 0 | 0.00 |
| 46 | 0 | 0 | 0 | 0 | 0.00 |
| 47 | 0 | 0 | 0 | 0 | 0.00 |
| 48 | 0 | 0 | 0 | 0 | 0.00 |
| 49 | 0 | 0 | 0 | 0 | 0.00 |
| 50 | 0 | 0 | 0 | 0 | 0.00 |

the reported failures were attributable to mechanical failure (13). If it is assumed that repair costs for mechanical failure are less than half the cost of major field reconstruction, and given the proportional breakdown of predicted costs for Amherst (see below), this translates into an increase of less than 3% over the costs predicted by the model. Therefore, omitting these costs will not significantly alter the predicted costs, and corrections to the program may be made after a few years' accumulation of minor repair data.

Analysis of the costs of major repairs during the study period yielded somewhat surprising results. Repair jobs appear to be priced in a manner reflecting the job type rather than the job size. That is, costs varied little for all the work done on leach fields, regardless of the leach field size; and similarly for repair work done on seepage pits of various volumes. Repairs to septic tanks as well as leach fields increase costs by a factor of 2-2.5 over repair jobs which entail renovation of disposal medium only. (See Figure 6.)

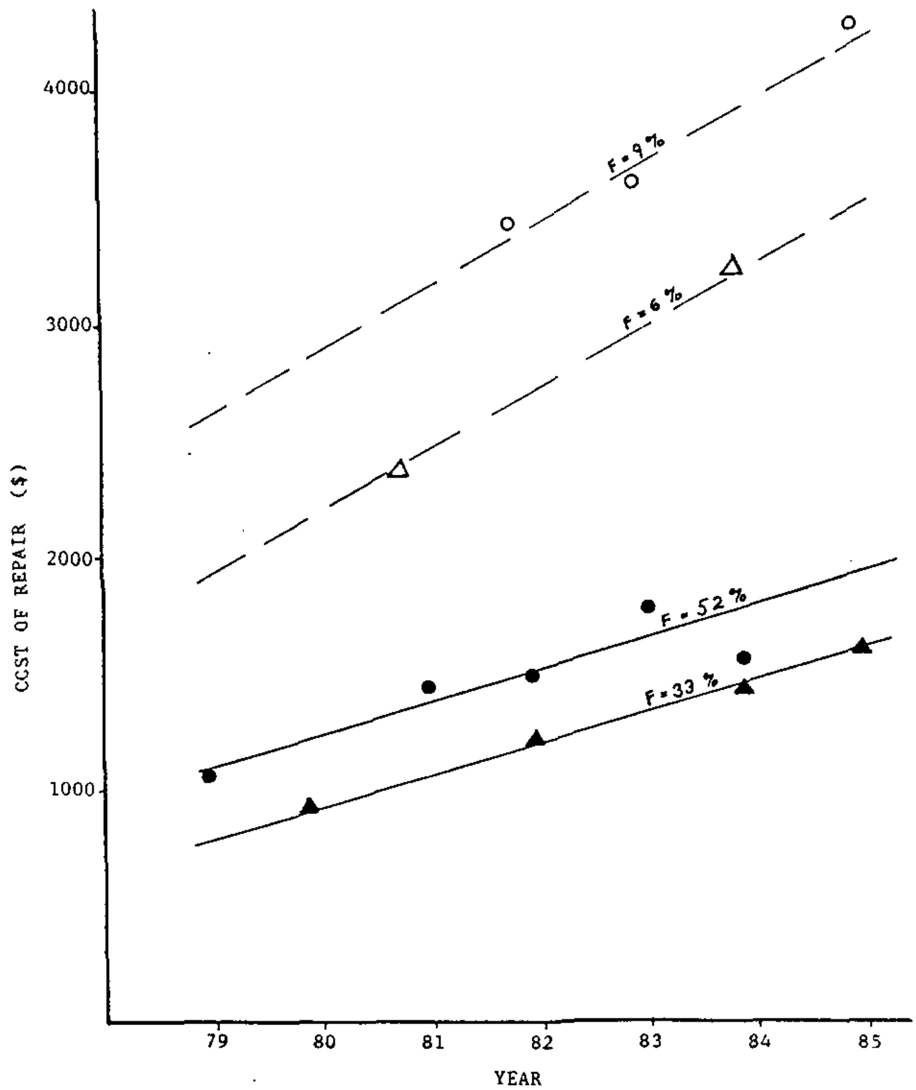
This pattern of pricing allows a simplification of future cost predictions. Utilizing 1985 dollars, and the frequency of occurrence data shown in Figure 6, one representative value for major repairs was obtained:

$$\text{Avg. Cost} = \sum_{i=1}^{N} \left(\begin{matrix}\text{frequency of}\\ \text{repair type } i\end{matrix}\right) * \left(\begin{matrix}\text{cost of}\\ \text{repair type } i\end{matrix}\right)$$

The resulting average cost per failure for Amherst is:

$$(.52)(1940) + (.33)(1630) + (.09)(4370) + (.06)(1630) = \$2160$$

Pumping costs are taken as $70 per tank pumpout, the current price charged by local septage haulers, and each tank is assumed pumped once every two years (approximately the current rate). If done on a regular basis, inspection is assumed to require no more than an hour per system, including travel, and so is priced at $20 per inspection. (Inspection costs will likely be higher in early years and lower later.) Each tank is assumed inspected every other year. Once the characteristic sludge accumulation rate is known, pumpout and inspection frequencies may be adjusted accordingly. Administrative costs for the maintenance program are valued initially at 25% of the sum of repairs, inspection, and pumping costs.




● Average cost of project which is predominantly leach field repair
▲ Average cost of project which is predominantly seepage pit repair
○ Average cost of project which is leach field and septic tank repair
△ Average cost of project which is seepage pit and septic tank repair
F = Frequency of occurrence of repair type

Figure 6 Septic System Repair Cost Curves for Amherst

## Predictive Model

An interactive computer program was written to predict future system failures using a projected future system installation sequence supplied by the user and information on the failure rates and age distribution of the existing systems. In this case, the age distribution of the existing septic systems was generated by the program discussed earlier. The age distribution was reprocessed to provide a new age distribution for each future year and to predict the number of new failures based on Amherst's septic system survival curve (Figure 5). Cost projections are then prepared for each year in the future based on failure repair costs and pumping, inspection, and administrative costs. This information is used to prepare an estimate of the per system annual cost in the first few years of operation of such a system. (The program is listed in the Appendix.) Sample output is listed in Table 3, using a projected installation rate obtained from Figure 4.

The annual cost per user for the next ten years is presented in Table 4. The average estimated cost per user (over the ten years simulated) is $108/yr. This compares favorably with the estimated current sewer use charge (per household) in Amherst of $98/yr. The cost of repairing failed systems accounts for approximately 40 percent of the total septic system management program cost. Thus the cost of a program which retained homeowner responsibility for repairs would cost about 40 percent less or approximately $65/yr.

TABLE 3

Performance Predictions

PERFORMANCE PREDICTIONS THROUGH 1994 :

| YEAR | NUMBER OF INSTALLATIONS | NUMBER OF FAILURES | NUMBER OF SYSTEMS IN USE | COST PER USER (in 1985 $'s) |
|---|---|---|---|---|
| 1985 | 56 | 11 | 494 | 116.00 |
| 1986 | 20 | 7 | 514 | 93.00 |
| 1987 | 20 | 7 | 534 | 92.00 |
| 1988 | 20 | 11 | 554 | 110.00 |
| 1989 | 15 | 12 | 569 | 113.00 |
| 1990 | 15 | 11 | 584 | 107.00 |
| 1991 | 15 | 10 | 599 | 101.00 |
| 1992 | 15 | 13 | 614 | 113.00 |
| 1993 | 15 | 13 | 629 | 112.00 |
| 1994 | 15 | 16 | 644 | 123.00 |

## TABLE 4

### Cost Breakdown for Amherst Maintenance Management Program

ANNUAL COST BREAKDOWN:
(in 1985 $'s)

| YEAR | REPAIR COST | PUMPING & INSPECTION COST | ADMIN. COST | TOTAL COST |
|---|---|---|---|---|
| 1985 | 23760.00 | 22230.00 | 11498.00 | 57490.00 |
| 1986 | 15120.00 | 23130.00 | 9563.00 | 47810.00 |
| 1987 | 15120.00 | 24030.00 | 9788.00 | 48940.00 |
| 1988 | 23760.00 | 24930.00 | 12173.00 | 60860.00 |
| 1989 | 25920.00 | 25605.00 | 12881.00 | 64410.00 |
| 1990 | 23760.00 | 26280.00 | 12510.00 | 62550.00 |
| 1991 | 21600.00 | 26955.00 | 12139.00 | 60690.00 |
| 1992 | 28080.00 | 27630.00 | 13928.00 | 69640.00 |
| 1993 | 28080.00 | 28305.00 | 14096.00 | 70480.00 |
| 1994 | 34560.00 | 28980.00 | 15885.00 | 79430.00 |

# 7. DISCUSSION

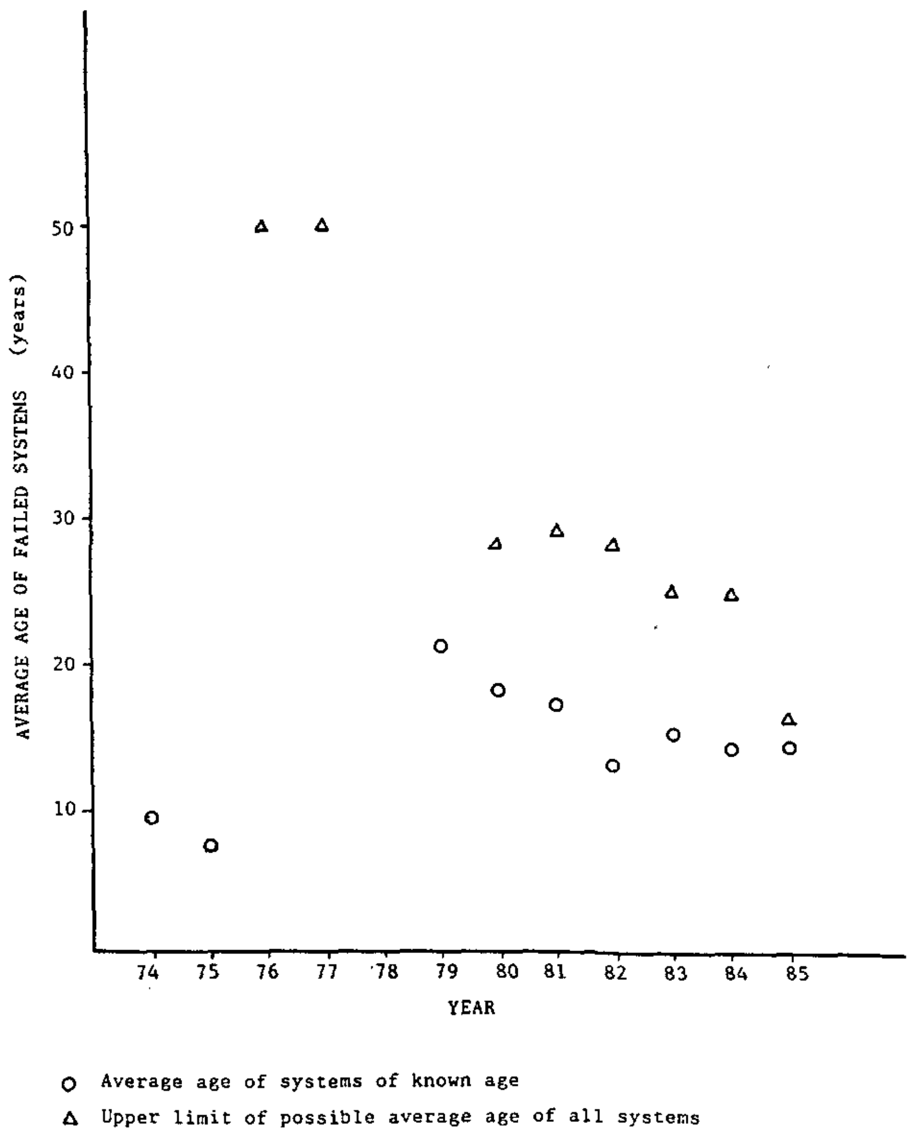
In the development of the preceding example of maintenance management in Amherst, the costs for three of the previously listed management plan components--site evaluation, system design, and construction inspection--were omitted. In Massachusetts, as in most states, these elements receive the bulk of the attention currently paid to septic systems. These functions are performed, adequately in most instances, by the appropriate local regulatory agencies, which either assume the cost or partially recover these costs via permitting fees. For this reason, this analysis was limited to the remaining three elements--monitoring, pumping, and repair.

## Use of Survival Curve

When reviewing the Amherst data, it should be noted that the half-life of the Amherst systems is about 25 years. For a planner considering implementing a septic system maintenance management program, this should be the first information sought. The survival curve is the best means of assessing the overall suitability of a region to on-site disposal as historically practiced. To reach a prudent decision on the question of whether or not to sewer an area, this type of performance history is a necessary input.

An inordinately short half-life may render a management plan economically infeasible. The performance history of the systems in Amherst, however, is good enough to warrant maintaining them as a viable means of waste disposal.

One important result of analyzing growth patterns across the state, and borne out by the Amherst data, is noteworthy for planning purposes. In areas experiencing rapid recent growth, a simultaneous shift in the age distribution of their septic systems occurs. Depending on the shape of the septic system survival curve which characterizes a given area, failure rates may seem deceptively low for the first 10 or 15 years of a population growth spurt. However, as the average age of that body of systems moves toward the region's characteristic half-life age, a rapid upswing in failures in inevitable. A recent shift in the average age of systems at failure in Amherst (Figure 7) reveals just such a performance adjustment in response to the rapid recent influx of new systems into the general septic system population.




Note: 72% of all failed systems are of known age.
Pre-1979 values are unreliable due to small sample size.

Figure 7 Average Age at Failure for Amherst Septic Systems

If, as is often the case, performance predictions are founded on the conventional belief that failure rate is strictly a function of the total number of systems in operation, planners and health officials may be caught unprepared for what will certainly be viewed as an unexpected rapid increase in failure rate. Proper understanding of the nature of septic system failures and proper planning for the natural course of changes in septic system performance will help alleviate the increased environmental stress resulting from the aging of a large body of recently installed septic systems. A properly run pumping and maintenance plan should also favorably alter the shape of a given survival curve, thus further attenuating stresses due to septic system failures by increasing both the half-life and the upper age limit for a properly operating population of septic systems.

Predictive Value

Due to the possible changes in the survival curve, it may not be wise to predict septic system performance too far into the future. For this reason, performance forecasts for Amherst were carried out only 10 years into the future. It is assumed that changes in overall performance would occur slowly enough that predictions over this length of time would remain valid. In any case, most of the anticipated changes should be favorable, resulting in lower rather than higher future costs. Three examples follow.

1) As was stated earlier, pumping schedules will be adjusted as a characteristic sludge accumulation rate is determined. Since the initial pumping rate in the model is set conservatively at once every two years, it is likely that any changes will tend toward less frequent pumping.

2) As time goes on, administrative chores should diminish to the point where they entail primarily bookkeeping. Thus, the magnitude of administrative costs should either decrease or at least remain stable.

3) No economies of scale were considered. Under a town-wide septic tank pumping scheme, economies of scale are likely due to efficiencies in truck routing, truck utilization rate, and pumping scheduling. Depending on how pumping is accomplished (i.e., contracted out or done by the town), savings may also be accomplished by eliminating profits and more efficient use of manpower.

However likely these occurrences seem, it must be noted that some events may have adverse effects on general survival rates. Chief among these is the continued development of land that is marginally suited to subsurface sewage disposal. It remains to be seen whether improved maintenance practices will have a more significant impact on overall system performance, but recognition of the existence of a negative influence makes development of an effective maintenance plan all the more prudent. It is also likely that there are some septic systems which are borderline failures. As long as repair costs are borne by the homeowner repairs to these will be postponed. As soon as municipal responsibility for repairs is instituted, however, the homeowners will decide the problems must be fixed right away. This would increase the cost of the septic system maintenance management program in the early years, but need not be a strain on the program's resources if an appropriate priority system is used to determine the order of systems repaired.

Predicted fluctuations of maintenance management costs may be of use to the planner in developing a user fee payment schedule which is more uniform than that outlined in Table 3. In this way sudden jumps in the fee schedule can be avoided, and funds allocated for maintenance will be more readily available to counter small year-to-year failure rate deviations from the predicted values. With a sound data base, reassessment of the fee schedule may be necessary only every five to ten years.

## Economic Analysis

The user costs for a maintenance management plan developed with the Amherst data compare favorably both with user charges for other management plans, and with current local rates for sewer service. The Amherst data yields a predicted average annual user charge of \$108 over the next ten years. In Stinson Beach, California, an annual user fee of \$120 is charged. Although the services at Stinson Beach include an extensive surface and groundwater quality monitoring program, system repair costs are still borne by the user. In Amherst, a sewer fee of \$.96/100 cu. ft. of sewage is charged. If Amherst's daily per capita waste discharge is 60 gallons and an average household contains 3.5 people, the approximate annual sewer fee would be:

$$\frac{(3.5\text{ people})(60\text{ gpcd})(\$.96/100\text{ cu. ft.})(365\text{ day/yr.})}{(7.48\text{ gal/cu. ft.})(100)} = \$98/\text{yr}$$

For a comparable fee, septic system users are relieved of the burden of large unexpected repair costs, and the risk to the water supply of the general population is minimized.

## 8. RECOMMENDATIONS

A review of literature pertinent to Massachusetts' needs and to subsurface disposal in general, and an analysis of septic system operation in Amherst, lead to several recommendations concerning on-site disposal practices in Massachusetts. These recommendations fall into three general categories: pre-operation design, post-installation maintenance, and septic system maintenance management structure.

### Pre-Operation Design

- Local health agencies should include or have access to a registered sanitarian trained in soils science and subsurface disposal. This service could be provided by DEQE regional offices, by counties, or by cooperative local agreements as is sometimes done for building inspectors in small towns. DEQE should work to upgrade the expertise of local boards of health by offering short courses, training workshops, and technology transfer materials.

- DEQE should revise Title 5 to incorporate greater use of soils data, in concert with percolation tests, to facilitate improved system design and site evaluation. Alternatively, this information could be made part of a comprehensive guidance document prepared as part of the previous recommendation.

- DEQE should encourage the practice of installing dual leaching fields with an alternating dosing pattern in areas susceptible to rapid leach field clogging.

- DEQE should prohibit leach field installation in wet weather in soils prone to smearing.

### Post-Installation Maintenance

- The section of Title 5 that recommends annual cleaning should be amended to require pumping and cleaning as needed based on regularly scheduled inspections (at least once every three years).

- Septage haulers should be required to keep complete records, including dates, amounts pumped, and location and condition of the septic systems pumped. This information should be submitted to the Boards of Health in the respective towns served on an annual basis.

- Local Boards of Health should keep complete performance records of each septic system, including the original design, reconstruction or rehabilitation design, and reasons for failure or repair.

Maintenance Management Structure

- Reassess criteria for prioritization of wastewater management plans which are eligible for federal and state funding to facilitate the development of plans utilizing on-site systems. Since such eligibility is contingent upon local guarantees that the systems will be properly maintained, the MDWPC should make available technical and other assistance to local communities to help them establish their own septic system maintenance management programs.

- The MDWPC should foster an atmosphere conducive to the development of local septic system maintenance management programs. Technical expertise, organizational resources, and grant-writing skills can be used toward this end. Dissemination of information to local authorities regarding the funding, feasibility, and practical advantages of proper maintenance programs will allow them to develop plans suitable for their area.

- Seek local institutions most likely to adapt to public maintenance procedures. In Massachusetts it seems most likely that local Boards of Health or sewer commissions are best suited to this purpose.

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# APPENDIX

## CALCULATING SEPTIC SYSTEM FAILURE RATES

TABLE OF CONTENTS

# RAW DATA

The following data was collected from Amherst Board of Health records:

| Year | Number of Repairs | Year of Installation | Number of Permits for New Systems |
|---|---|---|---|
| 1985 | 5 | mid 60's | 56 |
| | | 63 | |
| | | 65 | |
| | | 83 | |
| | | ~69 | |
| 1984 | 9 | 78 | 43 |
| | | 64 | |
| | | 67 | |
| | | old | |
| | | 54 | |
| | | ~50 | |
| | | 76 | |
| | | 65 | |
| | | 50's | |
| 1983 | 8 | 70 | 31 |
| | | 74 | |
| | | ? | |
| | | 70 | |
| | | 65 | |
| | | 70 | |
| | | old | |
| | | 60's | |
| 1982 | 10 | 40's | 15 |
| | | 75 | |
| | | 75 | |
| | | 50's | |
| | | ~70 | |
| | | old | |
| | | 72 | |
| | | old | |
| | | ~56 | |
| | | ? | |

Raw data (continued)

| Year | Number of Repairs | Year of Installation | Number of Permits for New Systems |
|---|---|---|---|
| 1981 | 5 | ~70 | 15 |
| | | 65-70 | |
| | | old | |
| | | 76 | |
| | | 47 | |
| 1980 | 3 | 65 | 10 |
| | | ? | |
| | | 60 | |
| 1979 | 3 | 64 | 14 |
| | | 51 | |
| | | 60's | |
| 1978 | 1 | ? | 8 |
| 1977 | 1 | 1840's | 7 |
| 1976 | 4 | old | 24 |
| | | old | |
| | | old | |
| | | 73 | |
| 1975 | 1 | 68 | 18 |
| 1974 | 1 | 65 | 38 |

## COUNTING FAILURES FOR A KNOWN POPULATION

A defined population must be identified in order to calculate failure rates. Actual data was available for 1974-1985. Extrapolations of this data were made to 1962 for the calculation of failure rates and to 1935 for later use in historical simulations.

### Number of Systems Built each Year

Actual data on new septic system installations was available for 1974-1985 (1985 itself was not used). The text (Section 6, Figure 4) describes how the historical population record was used to extrapolate the number of new septic systems built each year. No attempt has been made to take into account yearly variations or the switching from septic systems to sewers. The values below for years prior to 1974 might best be interpreted as estimates of net new septic system installations. Furthermore, all systems built prior to 1935 have been treated as being installed since 1935. Statistically, this assumption makes no significant difference because the statistics do not recognize the extreme longevity of some very old systems.

| YEAR | # NEW SYSTEMS | YEAR | # NEW SYSTEMS | YEAR | # NEW SYSTEMS |
|---|---|---|---|---|---|
| 1985 | 56 | 1968 | 16 | 1951 | 2 |
| 84 | 43 | 67 | 16 | 50 | 2 |
| 83 | 31 | 66 | 12 | 49 | 2 |
| 82 | 15 | 65 | 8 | 48 | 2 |
| 81 | 15 | 64 | 6 | 47 | 2 |
| 80 | 10 | 63 | 5 | 46 | 2 |
| 79 | 14 | 62 | 4 | 45 | 2 |
| 78 | 8 | 61 | 4 | 44 | 2 |
| 77 | 7 | 60 | 4 | 43 | 2 |
| 76 | 24 | 59 | 4 | 42 | 2 |
| 75 | 18 | 58 | 4 | 41 | 2 |
| 74 | 38 | 57 | 4 | 40 | 2 |
| 73 | 17 | 56 | 3 | 39 | 2 |
| 72 | 17 | 55 | 3 | 38 | 1 |
| 71 | 17 | 54 | 3 | 37 | 1 |
| 70 | 17 | 53 | 2 | 36 | 1 |
| 69 | 17 | 52 | 2 | 35 | 1 |

| | | |
|---|---|---|
| Total systems 1/1/86 | 494 | (see Ref. 3) |
| Systems built '74-84 | 223 | |
| Systems built '62-73 | 152 | |
| Systems built pre-'62 | 63 | |

Failures and Age at Failure by Calendar Year
(for defined population)

The defined population (for the purposes of calculating failure rates) is all systems built from 1962 - 1984 (inclusive). Failure records for these systems are culled from the raw data and tabulated below. Data for systems aged 1-11 years (i.e. those built 1974-1984) is used to extrapolate the failure history for the systems built between 1962-1973 for the period 1962-1973 (since there is no data on system failures during this time period).

Failures by systems constructed since 1962

| Year of Failure | Date of Construction | Age at Failure |
|---|---|---|
| 1985 | 83 | 2 |
| | ~69 (69) | 16 |
| | 65 | 20 |
| | mid-60's (65) | 20 |
| | 63 | 22 |
| 1984 | 78 | 6 |
| | 76 | 8 |
| | 67 | 17 |
| | 65 | 19 |
| | 64 | 20 |
| 1983 | 74 | 9 |
| | 70 | 13 |
| | 70 | 13 |
| | 70 | 13 |
| | 65 | 18 |
| | mid-60's (65) | 18 |

| Year of Failure | Date of Construction | Age at Failure |
|---|---|---|
| 1982 | 75 | 7 |
| | 75 | 7 |
| | 72 | 10 |
| | 70 | 12 |
| 1981 | 76 | 5 |
| | ~70 (70) | 11 |
| | 65-70 (67) | 14 |
| 1980 | 65 | 15 |
| 1979 | 60's (65) | 14 |
| | 64 | 15 |
| 1976 | 73 | 3 |
| 1975 | 68 | 7 |
| 1974 | 65 | 9 |

Total 29 failures by systems constructed since 1962 during the period '74-'85 need: failures by systems constructed since 1962 during the period 1962-1973

-> extrapolate from performance of systems built since 1974 during the period 1974-1985:

'74-'85 1549 system years of septic system operation
'62-'73 794 system years of septic system operation

and

'74-'85 7 failures by systems constructed since 1974

therefore

expect (794/1549) * 7 = 3 failures during '62-'73 by systems constructed 1962-1973.

based on histogram of the 7 failures during 1974-1985, the 3 failures during 1962-1973 are assigned:

| age at failure | year of construction |
|---|---|
| 9 | 1962 |
| 7 | 1966 |
| 4 | 1964 |

## HISTOGRAM OF AGE AT FAILURE

(for systems built 1962-1984 over the period 1962-1985)

| AGE | Histogram | # of failures at AGE |
|---|---|---|
| 1 | \| | 0 |
| 2 | \|X | 1 |
| 3 | \|X | 1 |
| 4 | \|X | 1 |
| 5 | \|X | 1 |
| 6 | \|X | 1 |
| 7 | \|XXXX | 4 |
| 8 | \|X | 1 |
| 9 | \|XXX | 3 |
| 10 | \|X | 1 |
| 11 | \|X | 1 |
| 12 | \| | 0 |
| 13 | \|XXXX | 4 |
| 14 | \|XX | 2 |
| 15 | \|XX | 2 |
| 16 | \|X | 1 |
| 17 | \|X | 1 |
| 18 | \|XX | 2 |
| 19 | \|X | 1 |
| 20 | \|XXX | 3 |
| 21 | \| | 0 |
| 22 | \|X | 1 |
| 23 | \| | 0 |
| 24 | \| | 0 |

## CALCULATING # INSTALLED

# INSTALLED (at a given AGE) (COL. VII) = # Built AGE years ago (new installations plus replacements)
(new = COL. III)
(replacements = COL. IV)

\+

# Built at or before AGE years ago but failed after AGE years of operation
(COL. V)

−

# Built AGE years ago but which failed prior to 12/31/85 (because these are already counted in the preceding category at an earlier AGE
(COL. VI)

| I AGE | II Y | III # Built New | IV Replaced | V # Built at or Pre-Y but failed at AGE | VI # Built in Y but failed by 12/31/85 | VII # INSTALLED |
|---|---|---|---|---|---|---|
| 1 | 1984 | 43 | 9 | 0 | 0 | 52 |
| 2 | 1983 | 31 | 8 | 1 | 1 | 39 |
| 3 | 1982 | 15 | 10 | 1 | 0 | 26 |
| 4 | 1981 | 15 | 5 | 1 | 0 | 21 |
| 5 | 1980 | 10 | 3 | 1 | 0 | 14 |
| 6 | 1979 | 14 | 3 | 1 | 0 | 18 |
| 7 | 1978 | 8 | 1 | 4 | 1 | 12 |
| 8 | 1977 | 7 | 1 | 1 | 0 | 9 |
| 9 | 1976 | 24 | 4 | 3 | 2 | 29 |
| 10 | 1975 | 18 | 1 | 1 | 2 | 18 |
| 11 | 1974 | 38 | 1 | 1 | 1 | 39 |
| 12 | 1973 | 17 | 1 | 0 | 1 | 17 |
| 13 | 1972 | 17 | 0 | 4 | 1 | 20 |
| 14 | 1971 | 17 | 1 | 2 | 0 | 20 |
| 15 | 1970 | 17 | 0 | 2 | 5 | 14 |
| 16 | 1969 | 17 | 0 | 1 | 1 | 17 |
| 17 | 1968 | 16 | 1 | 1 | 1 | 17 |
| 18 | 1967 | 16 | 0 | 2 | 2 | 16 |
| 19 | 1966 | 12 | 0 | 1 | 1 | 12 |
| 20 | 1965 | 8 | 0 | 3 | 8 | 3 |
| 21 | 1964 | 6 | 0 | 0 | 3 | 3 |
| 22 | 1963 | 5 | 0 | 1 | 1 | 5 |
| 23 | 1962 | 4 | 0 | 0 | 1 | 3 |

check that total of COL. V = COL. VI = 32 = number of failures '62-85

## CONSTRUCTION OF A SEPTIC SYSTEM SURVIVAL CURVE

(for septic systems built between 1962-1984
which failed as of 12/31/85)

| I<br>AGE | II<br>#<br>INSTALLED | III<br># REACHING<br>AGE GROUP | IV<br># FAILED<br>AT AGE | V<br>QUOTIENT | VI<br>%<br>SURVIVAL | VII<br>%<br>FAILURE |
|---|---|---|---|---|---|---|
| 1 | 52 | 424 | 0 | 0.000 | 100.00 | 0.00 |
| 2 | 39 | 372 | 1 | 0.0027 | 99.73 | 0.27 |
| 3 | 26 | 333 | 1 | 0.0030 | 99.43 | 0.30 |
| 4 | 21 | 307 | 1 | 0.0033 | 99.10 | 0.33 |
| 5 | 14 | 286 | 1 | 0.0035 | 98.75 | 0.35 |
| 6 | 18 | 272 | 1 | 0.0037 | 98.38 | 0.37 |
| 7 | 12 | 254 | 4 | 0.0157 | 96.84 | 1.54 |
| 8 | 9 | 242 | 1 | 0.0041 | 96.45 | 0.40 |
| 9 | 29 | 233 | 3 | 0.0128 | 95.21 | 1.23 |
| 10 | 18 | 204 | 1 | 0.0049 | 94.74 | 0.47 |
| 11 | 39 | 186 | 1 | 0.0054 | 94.23 | 0.51 |
| 12 | 17 | 147 | 0 | 0.0000 | 94.23 | 0.00 |
| 13 | 20 | 130 | 4 | 0.0308 | 91.13 | 2.90 |
| 14 | 20 | 110 | 2 | 0.0182 | 89.47 | 1.66 |
| 15 | 14 | 90 | 2 | 0.0222 | 87.48 | 1.99 |
| 16 | 17 | 76 | 1 | 0.0132 | 86.33 | 1.15 |
| 17 | 17 | 59 | 1 | 0.0169 | 84.87 | 1.46 |
| 18 | 16 | 42 | 2 | 0.0476 | 80.83 | 4.04 |
| 19 | 12 | 26 | 1 | 0.0384 | 77.73 | 3.10 |
| 20 | 3 | 14 | 3 | 0.2143 | 61.07 | 16.66 |
| 21 | 3 | 11 | 0 | 0.0000 | 61.07 | 0.00 |
| 22 | 5 | 8 | 1 | 0.1250 | 53.44 | 7.63 |
| 23 | 3 | 3 | 0 | 0.0000 | 53.44 | 0.00 |

Steps for construction of the Survival Curve follow on the next page.

## METHOD OF CONSTRUCTION OF THE SURVIVAL CURVE
(after Winneberger, Ref. 32)

1. The number of septic systems installed during each year of the period of study must be determined and entered in Column II for the appropriate AGE. (from COL. VII on page A-8)

2. For each septic system failure recorded during the period of study, the original installation date must be determined. From this, the age of each system at failure is obtained and the failure entered in the appropriate spot in Col. IV (from COL. V on page A-8).

3. The cumulative total of number of systems installed for each AGE is calculated and entered in COL. III.

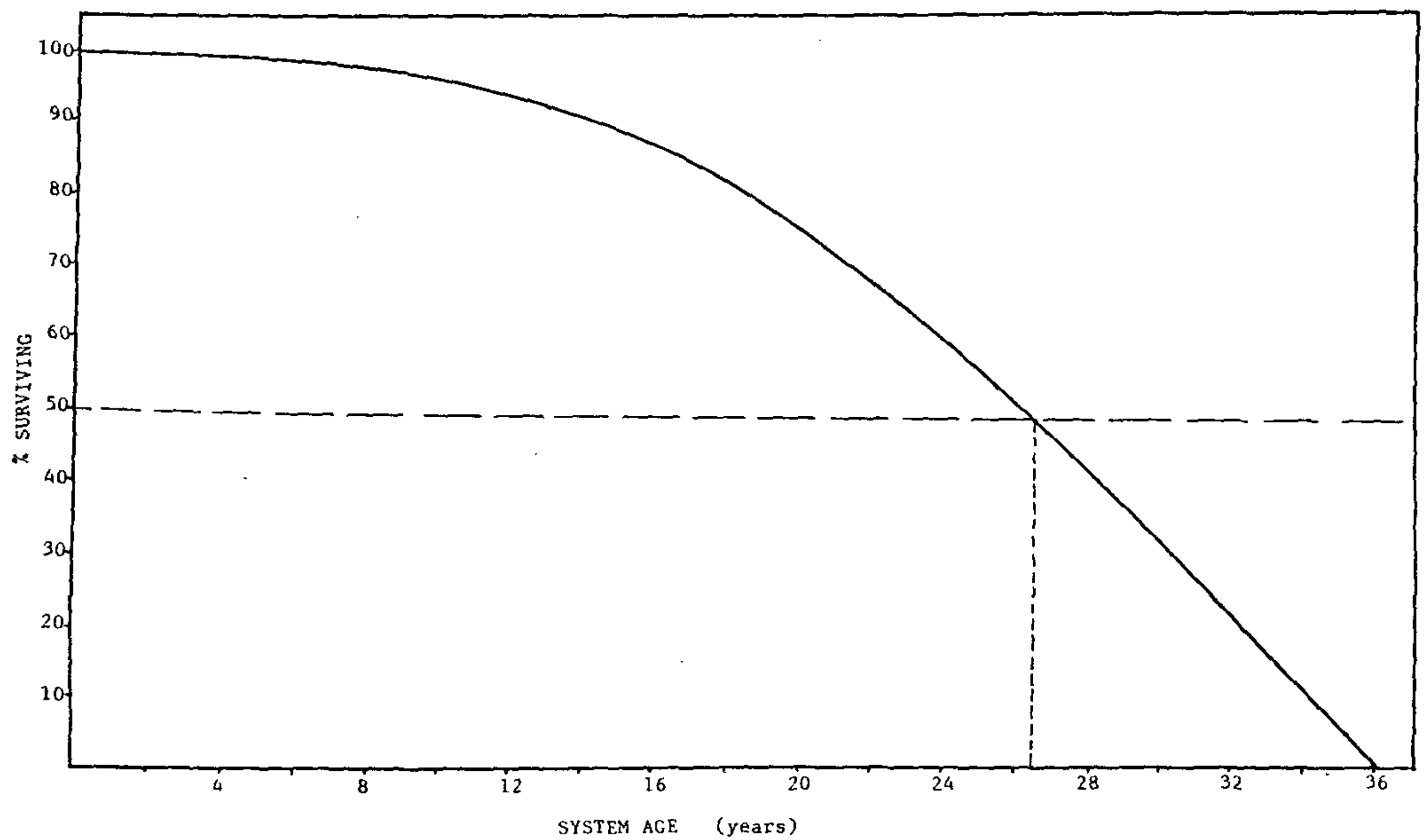
4. For each AGE, the quotient of the number failed (COL. IV) over the cumulative total reaching that AGE (COL. III) is obtained and entered in COL. V.

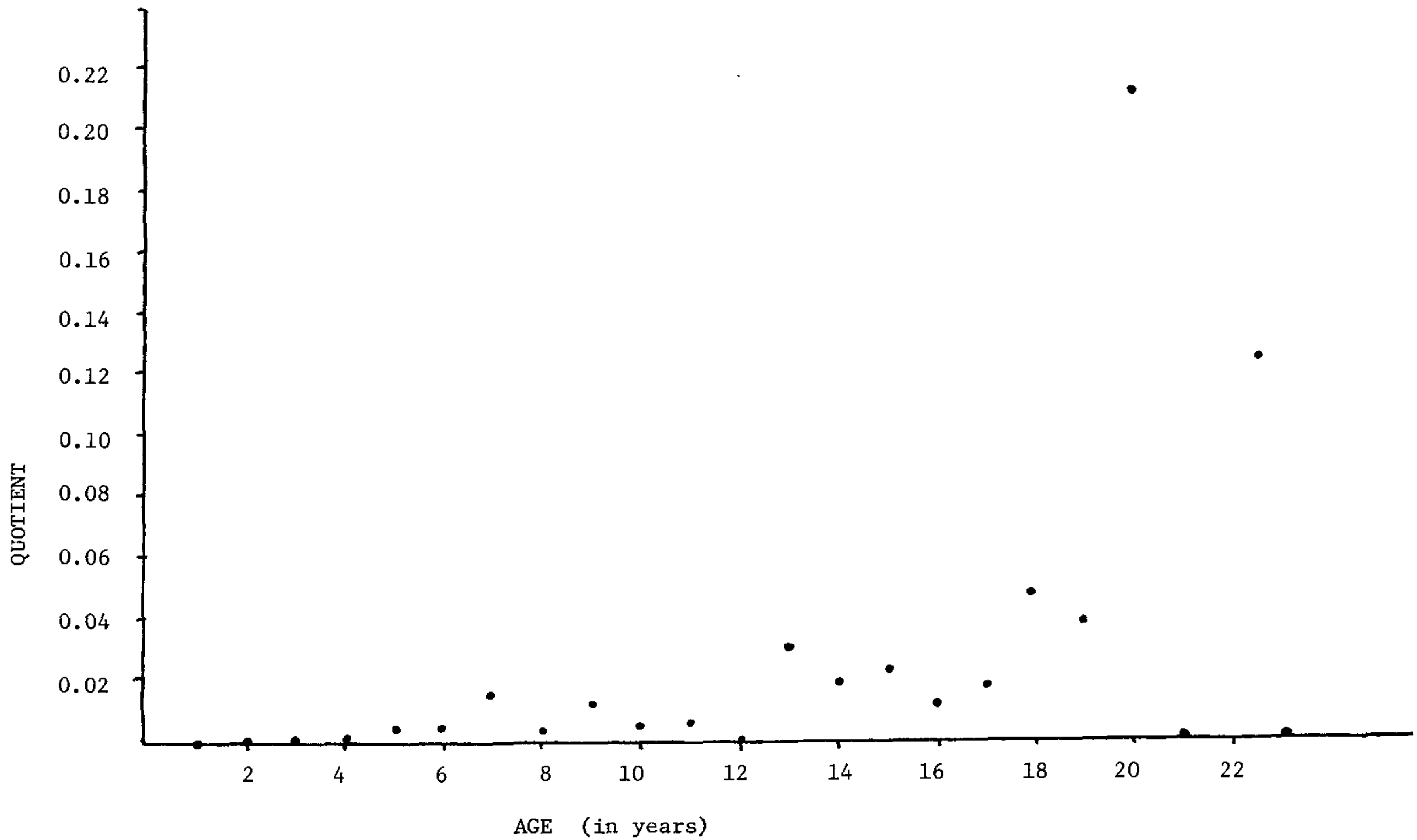
5. The quotient is multiplied by the % SURVIVING from the previous AGE to yield the failure rate for that AGE, which is entered in COL. VII.

6. The % FAILURE is subtracted from the % SURVIVING for each AGE to obtain the % SURVIVING for the following AGE, that is:
   $(\text{COL. VI})_i - (\text{COL. VII})_i = (\text{COL. VI})_{i+1}$

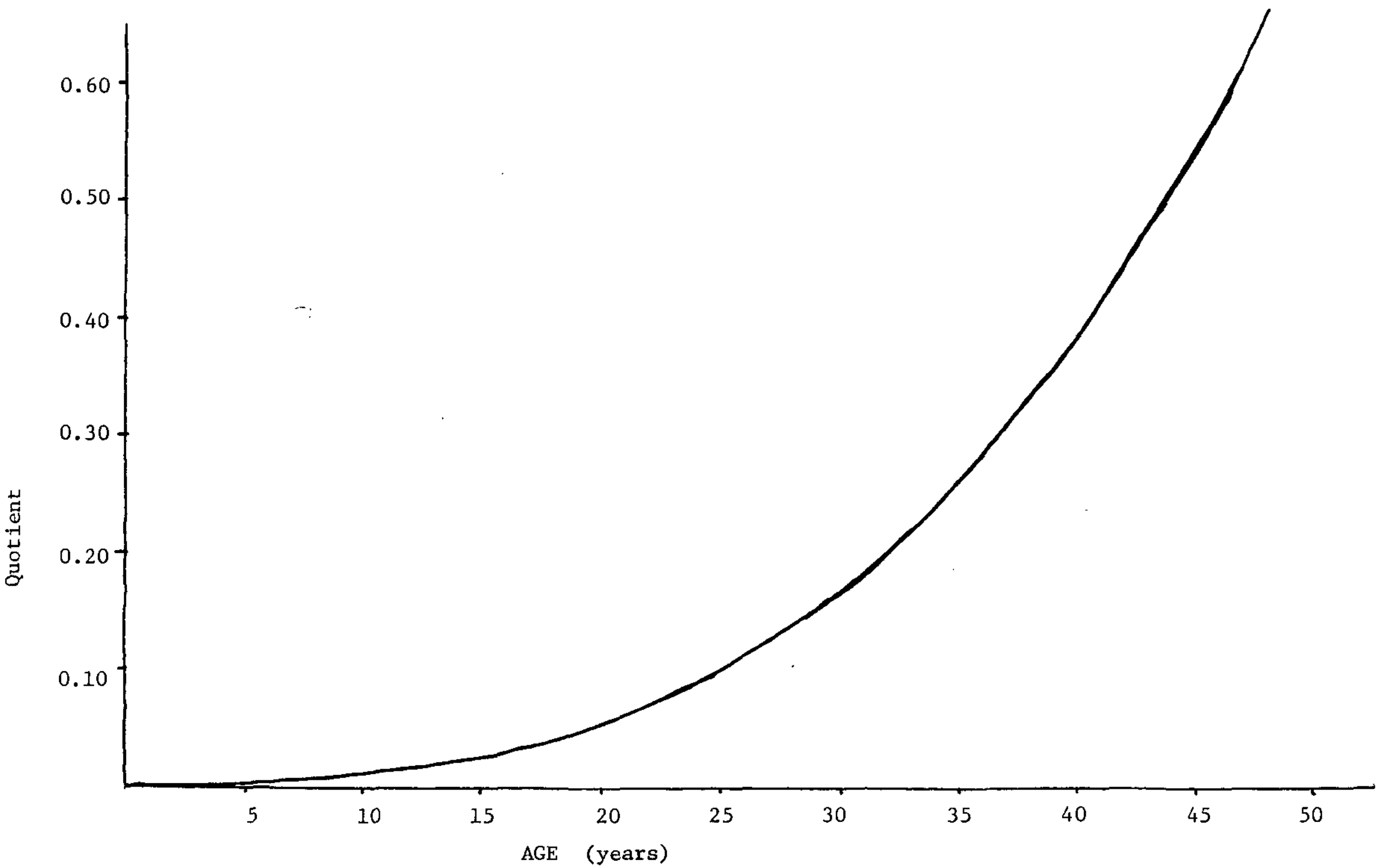
7. The above calculations are carried out for each successive year in the period of study, and the % SURVIVING each year are plotted vs. AGE.

Septic System Survival Curve for Amherst






Quotient vs. Age (calculated values)




Quotient vs. Age (extrapolated to 50 years)

## QUOTIENT vs. AGE

(Values interpolated from the previous figure.)

| AGE | QUOTIENT | AGE | QUOTIENT | AGE | QUOTIENT |
|---|---|---|---|---|---|
| 1 | .001 | 18 | .031 | 35 | .26 |
| 2 | .001 | 19 | .037 | 36 | .285 |
| 3 | .002 | 20 | .045 | 37 | .305 |
| 4 | .002 | 21 | .053 | 38 | .33 |
| 5 | .002 | 22 | .061 | 39 | .36 |
| 6 | .003 | 23 | .069 | 40 | .39 |
| 7 | .003 | 24 | .079 | 41 | .42 |
| 8 | .004 | 25 | .09 | 42 | .45 |
| 9 | .005 | 26 | .105 | 43 | .48 |
| 10 | .007 | 27 | .115 | 44 | .51 |
| 11 | .008 | 28 | .13 | 45 | .54 |
| 12 | .011 | 29 | .15 | 46 | .58 |
| 13 | .013 | 30 | .165 | 47 | .625 |
| 14 | .015 | 31 | .18 | 48 | .675 |
| 15 | .018 | 32 | .20 | 49 | .725 |
| 16 | .022 | 33 | .22 | 50 | .78 |
| 17 | .027 | 34 | .24 | | |

## SEPTIC SYSTEMS FAILURE SIMULATION MODEL

The following model was used to perform the simulation presented on the following pages. It is written in BASIC and requires 2-3 minutes running time on a Rainbow 100+ microcomputer for 50 years of input data. This model may be freely copied. To apply this model to other data, change the year counted as the present (line 100), the number of years of the simulation ("YR", line 110), the failure rate data for each year (lines 151-155), and the number of new systems installed each year (lines 230-250).

```
70 REM This program calculates septic system failure rates
71 REM according to the method presented by Winneberger, J. Env. Hlth.
72 REM pp. 36-39, July-Aug. 1975. Rate(i) corresponds to Quotient in his
73 REM method. Install%(n) is the number of new (brand new) systems
74 REM installed each year.
90 PRINT "Program running.  Please wait."
100 DATE = 1985
110 YR = 50
120 DIM TABLE%(4,YR)
130 DIM RATE(YR)
140 DIM INSTALL%(YR)
150 DIM FAIL%(YR,200)
151 DATA .001, .001, .002, .002, .002, .003, .003, .004, .005, .007
152 DATA .008, .011, .013, .015, .018, .022, .027, .031, .037, .045
153 DATA .053, .061, .069, .079, .090, .105, .115, .130, .150, .165
154 DATA .180, .200, .220, .240, .260, .285, .305, .330, .360, .390
155 DATA .420, .450, .480, .510, .540, .580, .625, .675, .725, .780
200 FOR I= 1 TO YR
210 READ RATE(I)
220 NEXT I
230 DATA 1,1,1,1,2,2,2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 3, 3
240 DATA 3, 4, 4, 4, 4, 4, 4, 5, 6, 8, 12, 16, 16, 17, 17, 17, 17
250 DATA 17, 38, 18, 24, 7, 8, 14, 10, 15, 15, 31, 43
260 FOR N= 1 TO YR
270 READ INSTALL%(N)
280 NEXT N
285 LPRINT "YEAR", "# FAILED", "  AGES OF FAILURES"
290 FOR S = 1 TO YR
300 TABLE%(1,YR) = TABLE%(1,YR) + TABLE%(1,YR-1)
310 TABLE%(2,YR) = TABLE%(1,YR) + TABLE%(4,YR)
320 TABLE%(3,YR) = TABLE%(2,YR)
330 FOR Q = YR-1 TO 2 STEP -1
340 TABLE%(1,Q) = TABLE%(1,Q-1)
350 TABLE%(2,Q) = TABLE%(1,Q) + TABLE%(4,Q)
360 TABLE%(3,Q) = TABLE%(3,Q+1) + TABLE%(2,Q)
```

```
370 NEXT Q
380 TABLE%(1,1) = INSTALL%(S)
390 TABLE%(2,1) = TABLE%(1,1) + TABLE%(4,1)
400 TABLE%(3,1) = TABLE%(3,2) + TABLE%(2,1)
410 FOR P = 1 TO YR
420 X = RATE(P) * TABLE%(3,P)
430 Y = CINT(X)
440 Z = Y - TABLE%(4,P)
450 IF Z <= 0 THEN GOTO 530
460 FOR T = 1 TO Z
470 TABLE%(4,P) = TABLE%(4,P) + 1
480 TABLE%(1,P) = TABLE%(1,P) - 1
490 FAIL%(S,0) = FAIL%(S,0) + 1
500 FAIL%(S,FAIL%(S,0)) = P
510 IF S < YR THEN INSTALL%(S+1) = INSTALL%(S+1) + 1 ELSE GOTO 520
520 NEXT T
530 NEXT P
532 IF FAIL%(S,0) <= 0 THEN GOTO 540
533 LPRINT DATE-YR+S,FAIL%(S,0),
534 FOR A = 1 TO FAIL%(S,0)
535 LPRINT FAIL%(S,A);
536 NEXT A
537 LPRINT " "
540 NEXT S
545 LPRINT " "
546 LPRINT " "
550 K = 100
560 LPRINT "AGE DISTRIBUTION OF SYSTEMS, AS OF DECEMBER 31, 1985:"
570 LPRINT " "
571 LPRINT " "
572 LPRINT "COL: I","  II"," III","  IV","  V","  VI"
580 LPRINT "AGE","NUMBER STILL", "NUMBER", "CUMULATIVE", "NUMBER OF","%"
590 LPRINT "  ","WORKING","INSTALLED","TOTAL","FAILURES","SURVIVING"
600 FOR B = 1 TO YR
610 IF TABLE%(3,B)>0 THEN L=TABLE%(4,B)/TABLE%(3,B) ELSE L = 0
620 UNITS = UNITS + TABLE%(1,B)
630 M = K*L
640 K = K-M
650 LPRINT B,TABLE%(1,B),TABLE%(2,B),TABLE%(3,B),TABLE%(4,B),
660 LPRINT USING "###.##";K
670 NEXT B
680 UNITS = UNITS + FAIL%(YR,0)
681 LPRINT " "
682 LPRINT "NUMBER WHICH FAILED IN THE LAST YEAR OF THE SIMULATION"
684 LPRINT "(AND THEREFORE HAVE AGE = 0) AND ARE NOT INCLUDEDD IN"
686 LPRINT "COLUMN II OF THE TABLE: ";FAIL%(YR,0)
688 LPRINT" "
690 LPRINT "   "
700 LPRINT "TOTAL UNITS IN OPERATION: ", UNITS
710 OPEN "o",#1,"data1"
720 OPEN "o",#2,"data2"
725 WRITE #1, UNITS, DATE, YR, FAIL%(YR,0)
730 FOR J= 1 TO YR
740 WRITE #1,TABLE%(1,J),TABLE%(2,J),TABLE%(3,J),TABLE%(4,J)
750 WRITE #2,RATE(J)
760 NEXT J
780 CLOSE #1
790 CLOSE #2
800 END
```

## SIMULATION OF A KNOWN POPULATION

The Septic Systems Failure Simulation Model was applied to the 24 years of "known" data used on pages A-5 through A-11. The results are presented below and compared with the actual data on the following page.

AGE DISTRIBUTION OF SYSTEMS, AS OF DECEMBER 31, 1985:

| COL: I AGE | II NUMBER STILL WORKING | III NUMBER INSTALLED | IV CUMULATIVE TOTAL | V NUMBER OF FAILURES | VI % SURVIVING |
|---|---|---|---|---|---|
| 1 | 47 | 47 | 400 | 0 | 100.00 |
| 2 | 33 | 33 | 353 | 0 | 100.00 |
| 3 | 17 | 18 | 320 | 1 | 99.69 |
| 4 | 20 | 21 | 302 | 1 | 99.36 |
| 5 | 13 | 14 | 281 | 1 | 99.00 |
| 6 | 18 | 19 | 267 | 1 | 98.63 |
| 7 | 6 | 7 | 248 | 1 | 98.24 |
| 8 | 7 | 8 | 241 | 1 | 97.83 |
| 9 | 24 | 25 | 233 | 1 | 97.41 |
| 10 | 18 | 19 | 208 | 1 | 96.94 |
| 11 | 35 | 37 | 189 | 2 | 95.91 |
| 12 | 16 | 18 | 152 | 2 | 94.65 |
| 13 | 16 | 18 | 134 | 2 | 93.24 |
| 14 | 16 | 18 | 116 | 2 | 91.63 |
| 15 | 14 | 16 | 98 | 2 | 89.76 |
| 16 | 15 | 17 | 82 | 2 | 87.57 |
| 17 | 14 | 16 | 65 | 2 | 84.88 |
| 18 | 14 | 16 | 49 | 2 | 81.41 |
| 19 | 9 | 10 | 33 | 1 | 78.95 |
| 20 | 7 | 8 | 23 | 1 | 75.51 |
| 21 | 3 | 4 | 15 | 1 | 70.48 |
| 22 | 2 | 3 | 11 | 1 | 64.07 |
| 23 | 3 | 4 | 8 | 1 | 56.06 |
| 24 | 4 | 4 | 4 | 0 | 56.06 |

NUMBER WHICH FAILED IN THE LAST YEAR OF THE SIMULATION (AND THEREFORE HAVE AGE = 0) AND ARE NOT INCLUDED IN COLUMN II OF THE TABLE: 8

TOTAL UNITS IN OPERATION: 379

## SIMULATION OF A KNOWN POPULATION
(continued)

Comparison of Model Results with Actual Data
(Systems built since 1962)

| YEAR | # FAILED ACTUAL | MODEL |
|---|---|---|
| 1985 | 5 | 8 |
| 1984 | 5 | 4 |
| 1983 | 6 | 2 |
| 1982 | 4 | 2 |
| 1981 | 3 | 5 |
| 1980 | 1 | 3 |
| 1979 | 2 | 5 |
| 1978 | 0 | 0 |
| 1977 | 0 | 0 |
| 1976 | 1 | 0 |
| 1975 | 1 | 0 |
| 1974 | 1 | 0 |
| 1973 ) | | 0 |
| ^ ) | | 0 |
| \| ) | 3 (est) | 0 |
| v ) | | 0 |
| 1962 ) | | 0 |
| TOTAL | 32 | 29 |

AGE AT FAILURE

| AGE | ACTUAL | AGE | MODEL |
|---|---|---|---|
| 1 | | 1 | |
| 2 | X | 2 | |
| 3 | X | 3 | X |
| 4 | | 4 | X |
| 5 | X | 5 | X |
| 6 | X | 6 | X |
| 7 | XXX | 7 | X |
| 8 | X | 8 | X |
| 9 | XX | 9 | X |
| 10 | X | 10 | X |
| 11 | X | 11 | XX |
| 12 | | 12 | XX |
| 13 | XXX | 13 | XX |
| 14 | XX | 14 | XX |
| 15 | XX | 15 | XX |
| 16 | X | 16 | XX |
| 17 | X | 17 | XX |
| 18 | XX | 18 | XX |
| 19 | X | 19 | X |
| 20 | XXX | 20 | X |
| 21 | | 21 | X |
| 22 | X | 22 | X |
| 23 | | 23 | X |
| 24 | | 24 | |

## SIMULATING THE HISTORICAL RECORD

The historical record of septic tank installations in Amherst was cast as a 50-year data record (page A-4) and simulated using 50 years of data. The predicted failures, by year, are presented below. The summary table is presented on the following page and in the text. (See Table II.)

The data on septic system failures collected for the years 1974-1985 includes a total of 50 failures, whereas the model predicts 59. This may indicate that the model slightly over predicts system failures (by less than one per year), but this cannot be asserted conclusively based on such a short time period comparison. The model mimics septic system failures, but because it is a stochastic model of failures it does not truly simulate them. Thus the model's accuracy improves when it is applied to longer time intervals.

It is also important to recognize that the model's "goodness" is limited by the quality of the data used in constructing it. That is, how representative are the data from 1974-1985 of the long term (especially future) performance of septic systems in Amherst? (A rhetorical question)

All things considered, we are pleased with the "goodness" of this model and feel that it does a more-than-satisfactory job of generating the estimates we desired.

AGE DISTRIBUTION OF SYSTEMS, AS OF DECEMBER 31, 1985:

| COL: I AGE | II NUMBER STILL WORKING | III NUMBER INSTALLED | IV CUMULATIVE TOTAL | V NUMBER OF FAILURES | VI % SURVIVING |
|---|---|---|---|---|---|
| 1 | 45 | 46 | 508 | 1 | 99.80 |
| 2 | 37 | 37 | 462 | 0 | 99.80 |
| 3 | 23 | 24 | 425 | 1 | 99.57 |
| 4 | 16 | 17 | 401 | 1 | 99.32 |
| 5 | 15 | 16 | 384 | 1 | 99.06 |
| 6 | 17 | 18 | 368 | 1 | 98.79 |
| 7 | 12 | 13 | 350 | 1 | 98.51 |
| 8 | 11 | 12 | 337 | 1 | 98.22 |
| 9 | 28 | 30 | 325 | 2 | 97.61 |
| 10 | 22 | 24 | 295 | 2 | 96.95 |
| 11 | 40 | 42 | 271 | 2 | 96.24 |
| 12 | 17 | 20 | 229 | 3 | 94.98 |
| 13 | 17 | 20 | 209 | 3 | 93.61 |
| 14 | 17 | 20 | 189 | 3 | 92.13 |
| 15 | 14 | 17 | 169 | 3 | 90.49 |
| 16 | 18 | 21 | 152 | 3 | 88.70 |
| 17 | 16 | 20 | 131 | 4 | 86.00 |
| 18 | 14 | 17 | 111 | 3 | 83.67 |
| 19 | 10 | 13 | 94 | 3 | 81.00 |
| 20 | 7 | 11 | 81 | 4 | 77.00 |
| 21 | 7 | 11 | 70 | 4 | 72.60 |
| 22 | 6 | 10 | 59 | 4 | 67.68 |
| 23 | 6 | 9 | 49 | 3 | 63.54 |
| 24 | 1 | 4 | 40 | 3 | 58.77 |
| 25 | 4 | 7 | 36 | 3 | 53.87 |
| 26 | 1 | 4 | 29 | 3 | 48.30 |
| 27 | 2 | 5 | 25 | 3 | 42.50 |
| 28 | 0 | 3 | 20 | 3 | 36.13 |
| 29 | 0 | 3 | 17 | 3 | 29.75 |
| 30 | 2 | 4 | 14 | 2 | 25.50 |
| 31 | 1 | 3 | 10 | 2 | 20.40 |
| 32 | 0 | 1 | 7 | 1 | 17.49 |
| 33 | 1 | 2 | 6 | 1 | 14.57 |
| 34 | 0 | 1 | 4 | 1 | 10.93 |
| 35 | 0 | 1 | 3 | 1 | 7.29 |
| 36 | 0 | 1 | 2 | 1 | 3.64 |
| 37 | 0 | 0 | 1 | 0 | 3.64 |
| 38 | 0 | 0 | 1 | 0 | 3.64 |
| 39 | 0 | 0 | 1 | 0 | 3.64 |
| 40 | 0 | 0 | 1 | 0 | 3.64 |
| 41 | 0 | 0 | 1 | 0 | 3.64 |
| 42 | 0 | 0 | 1 | 0 | 3.64 |
| 43 | 0 | 0 | 1 | 0 | 3.64 |
| 44 | 0 | 1 | 1 | 1 | 0.00 |
| 45 | 0 | 0 | 0 | 0 | 0.00 |
| 46 | 0 | 0 | 0 | 0 | 0.00 |
| 47 | 0 | 0 | 0 | 0 | 0.00 |
| 48 | 0 | 0 | 0 | 0 | 0.00 |
| 49 | 0 | 0 | 0 | 0 | 0.00 |
| 50 | 0 | 0 | 0 | 0 | 0.00 |

NUMBER WHICH FAILED IN THE LAST YEAR OF THE SIMULATION (AND THEREFORE HAVE AGE = 0) AND ARE NOT INCLUDED IN COLUMN II OF THE TABLE: 11

TOTAL UNITS IN OPERATION: 438

## SIMULATING TO PROJECT FUTURE FAILURES

The model below uses the results of the previous model (stored in two data files) to project septic system failures for a specified future period. The predictions of future failures are combined with economic data to project the costs of a septic system maintenance management program for those years. Future septic system installations are entered interactively. The economic data is embedded in the program. The current values are: cost per inspection = $20, cost for pumping = $70, cost of repair of failed system = $2160, administrative costs = 25%, and the pumping and inspection frequencies are once every two years.

```
100 REM Program to predict future septic system performance
105 REM
110 REM  Requires previous program to be run first to create
120 REM the data files "data1" and "data2"
130 REM
140 INSPECTCOST = 20
150 PUMPCOST = 70
160 REPCOST = 2160
165 ADMINRATE = .25
170 PUMPFREQ = 2
175 INSPFREQ = 2
200 OPEN"I",#1,"data1"
210 OPEN"I",#2,"data2"
220 INPUT #1, UNITS, DATE, YR, LASTFAIL
222 DIM TABLE%(4,YR)
224 DIM RATE(YR)
230 FOR I = 1 TO YR
240 INPUT #1, TABLE%(1,I), TABLE%(2,I), TABLE%(3,I), TABLE%(4,I)
250 INPUT #2, RATE(I)
260 NEXT I
270 CLOSE #1
280 CLOSE #2
290 INPUT "What is the final year under study?"; FINAL
300 REM DIM INSTALL%(FINAL-DATE)
310 DIM FAIL%(FINAL-DATE+1)
320 DIM SYST%(FINAL-DATE)
330 DIM COST%(FINAL-DATE+1,5)
340 DIM UNITS%(FINAL-DATE+1)
350 UNITS%(0) = UNITS
360 FAIL%(0) = LASTFAIL
370 FOR J = 0 TO FINAL-DATE
380 PRINT "Input number of new systems installed in"; DATE+J;
390 INPUT SYST%(J)
400 INSTALL%(J) = SYST%(J)
410 NEXT J
420 LPRINT " ", "PERFORMANCE PREDICTIONS THROUGH "; FINAL; ":"
430 LPRINT " "
```

```
440 LPRINT "YEAR","NUMBER OF","NUMBER OF","NUMBER OF","COST PER"
450 LPRINT " ","INSTALLATIONS","FAILURES","SYSTEMS","USER"
460 LPRINT " "," "," ","IN USE","(in 1985 $'s)"
470 FOR S = 0 TO FINAL-DATE
480 TABLE%(1,YR) = TABLE%(1,YR) + TABLE%(1,YR-1)
490 TABLE%(2,YR) = TABLE%(2,YR) + TABLE%(4,YR)
500 TABLE%(3,YR) = TABLE%(2,YR)
510 FOR Q = YR-1 TO 2 STEP -1
520 TABLE%(1,Q) = TABLE%(1,Q-1)
530 TABLE%(2,Q) = TABLE%(1,Q) + TABLE%(4,Q)
540 TABLE%(3,Q) = TABLE%(3,Q+1) + TABLE%(2,Q)
550 NEXT Q
560 TABLE%(1,1) = INSTALL%(S)
570 TABLE%(2,1) = TABLE%(1,1) + TABLE%(4,1)
580 TABLE%(3,1) = TABLE%(3,2) + TABLE%(2,1)
590 FOR P = 1 TO YR
600 X = RATE(P) * TABLE%(3,P)
610 Y = CINT(X)
620 Z = Y - TABLE%(4,P)
630 IF Z <= 0 THEN GOTO 700
640 FOR T = 1 TO Z
650 TABLE%(4,P) = TABLE%(4,P) + 1
660 TABLE%(1,P) = TABLE%(1,P) - 1
670 FAIL%(S+1) = FAIL%(S+1) + 1
680 IF S < FINAL-DATE THEN INSTALL%(S+1) = INSTALL%(S+1) + 1
690 NEXT T
700 NEXT P
710 UNITS%(S+1) = UNITS%(S) + SYST%(S)
720 REM cost calculations
730 COST%(S,1) = REPCOST * FAIL%(S)/10
740 COST%(S,2) = (PUMPCOST/PUMPFREQ + INSPECTCOST/INSPFREQ) * UNITS%(S+1)
750 COST%(S,3) = ADMINRATE * (COST%(S,1)*10 + COST%(S,2))
760 COST%(S,4) = (COST%(S,1)*10 + COST%(S,2) + COST%(S,3))/10
770 COST%(S,5) = COST%(S,4)*10/UNITS%(S+1)
780 REM
790 LPRINT DATE+S,SYST%(S),FAIL%(S),UNITS%(S+1),
800 LPRINT USING "#####.##";COST%(S,5)
810 NEXT S
820 LPRINT " "
830 LPRINT "                ANNUAL COST BREAKDOWN:"
840 LPRINT "                (in 1985 $'s)"
850 LPRINT " "
860 LPRINT "YEAR","REPAIR","PUMPING &","ADMIN.","TOTAL"
870 LPRINT " ","COST","INSPECTION","COST","COST"
880 LPRINT " "," ","COST"
890 LPRINT " "
900 FOR K = 0 TO FINAL-DATE
910 LPRINT DATE+K,
920 C1 = COST%(K,1)*10
922 C2 = COST%(K,2)
923 C3 = COST%(K,3)
924 C4 = COST%(K,4)*10
930 LPRINT USING "######.##    ";C1,C2,C3,C4
950 NEXT K
960 END
```

# OUTPUT FROM THE PROGRAM TO PROJECT FUTURE SEPTIC SYSTEM FAILURES

PERFORMANCE PREDICTIONS THROUGH 1994 :

| YEAR | NUMBER OF INSTALLATIONS | NUMBER OF FAILURES | NUMBER OF SYSTEMS IN USE | COST PER USER (in 1985 $'s) |
|---|---|---|---|---|
| 1985 | 56 | 11 | 494 | 116.00 |
| 1986 | 20 | 7 | 514 | 93.00 |
| 1987 | 20 | 7 | 534 | 92.00 |
| 1988 | 20 | 11 | 554 | 110.00 |
| 1989 | 15 | 12 | 569 | 113.00 |
| 1990 | 15 | 11 | 584 | 107.00 |
| 1991 | 15 | 10 | 599 | 101.00 |
| 1992 | 15 | 13 | 614 | 113.00 |
| 1993 | 15 | 13 | 629 | 112.00 |
| 1994 | 15 | 16 | 644 | 123.00 |

ANNUAL COST BREAKDOWN:
(in 1985 $'s)

| YEAR | REPAIR COST | PUMPING & INSPECTION COST | ADMIN. COST | TOTAL COST |
|---|---|---|---|---|
| 1985 | 23760.00 | 22230.00 | 11498.00 | 57490.00 |
| 1986 | 15120.00 | 23130.00 | 9563.00 | 47810.00 |
| 1987 | 15120.00 | 24030.00 | 9788.00 | 48940.00 |
| 1988 | 23760.00 | 24930.00 | 12173.00 | 60860.00 |
| 1989 | 25920.00 | 25605.00 | 12881.00 | 64410.00 |
| 1990 | 23760.00 | 26280.00 | 12510.00 | 62550.00 |
| 1991 | 21600.00 | 26955.00 | 12139.00 | 60690.00 |
| 1992 | 28080.00 | 27630.00 | 13928.00 | 69640.00 |
| 1993 | 28080.00 | 28305.00 | 14096.00 | 70480.00 |
| 1994 | 34560.00 | 28980.00 | 15885.00 | 79430.00 |