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EFFECTIVE USE OF HIGH WATER TAB AREAS FOR SANITARY LANDFILL. VOLUME I

R. A. Beluche, et al

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The objective of this project was to demonstrate that a landfill in a high water table area could be satisfactorily engineered and operated to produce a minimal impact on the surrounding environment. Initial input was centered on design and site engineering. Subsequent evaluation included detailed accumulation and analysis of physical, chemical and biological data on surface and groundwater parameters both on and off site. The site development included two types of disposal areas to evaluate engineering, operation, cost and environmental assessment. Demonstration cells were in an area that had been dewatered. Control cells were in an undrained area and penetrated the shallow aquifer with some waste deposited below the water table. A geologic and hydrologic evaluation of the site was also performed in order to determine the interconnection of the shallow aquifer with the Floridian aquifer. The report contains data accumulated over a two year period after initial refuse was deposited. Additional monitoring is planned and scheduled to data input for a period of three more years.

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EFFECTIVE USE OF HIGH WATER TABLE AREAS FOR SANITARY LANDFILL

Final Report

Volume I

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Orange County, Florida
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ACKNOWLEDGEMENT

This is a Final Report of a three-year demonstration project, authorized by the Board of County Commissioners, Orange County, Florida, and funded in part by Grant No. S-802283, from the Environmental Protection Agency, Office of Solid Waste Management Programs. It is an important element of the County's Solid Waste Disposal Program. The program is under the responsibility and authority of Mr. C. L. Goode, Public Works Administrator, and under the supervision of Mr. M. W. Hall, Superintendent, Solid Waste Disposal System.

Orange County retains VTN INC. for planning and engineering and management consultant services concerned with the orderly progress of the Solid Waste Disposal Program. These services include the master planning for the landfill site, the design of landfill improvements, the selection of equipment, and the formulation of recommendations for operational procedures.

The Solid Waste Disposal System, Orange County, provides the requisite personnel and equipment for the conduct of landfill operations and maintains accurate records concerning waste quantities handled and the construction and operation costs incurred. Mr. Gary J. Bergstrom, Biologist with the Orange County Pollution Control Department, under the supervision of Mr. C. W. Sheffield, County Pollution Control Officer, had the responsibility for sampling and testing surface and ground waters.

Faculty and students at Florida Technological University, working under the direction of Dr. Waldron McLellon, Civil Engineering and Environmental Sciences Department, monitored organic and bacteriological parameter changes resulting from sanitary landfill construction in a high water table area. Dr. David Vickers and Dr. Julius Charba of the Biological Sciences Department contributed significantly to the environmental assessment program. The Florida Technological University participants have conducted a thorough literature search and reviewed available information on similar disposal operations.

The U. S. Department of Agriculture, Soil Conservation Service, at the request of the Board of County Commissioners, assisted in the preparation of geological and soil studies at the demonstration site. In support of these studies, Mr. L. Orlando Rowland, a certified consulting geologist, prepared a supplemental study. Additionally, Ardaman and Associates, consulting soil scientists, prepared a report on surface soil, geological, and ground water conditions existing at the demonstration site. These studies were utilized in planning landfill improvements. Portions of the findings are incorporated in this report.

The assistance and cooperation extended by the many local, state and Federal officials who were contacted in matters related to the demonstration project are gratefully acknowledged.

Ramon A. Beluche, Ph.D.
Vice President, VTN INC., and
Demonstration Project Director

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SUMMARY

Recognizing the need for the proper management of solid waste, the Board of County Commissioners for Orange County, Florida, is presently implementing a long-range program for solid waste disposal in Orange County.

Sanitary landfilling has been and will continue to be for the next 15 years the method of solid waste disposal. An early problem facing implementation of the program, however, was the lack of available information on sanitary landfill operations in areas where a high ground water table is a dominating feature. To overcome this informational blank, the Board of County Commissioners made application to the U.S. Environmental Protection Agency for a Solid Waste Demonstration Grant to enable the County to carry out a three-year program of tests and operations in a high water table area such as would be encountered within Orange County. The application was subsequently approved and tests and operations began. This is a report covering the three years of the approved Demonstration Project titled 'Effective Use of High Water Table Areas for Sanitary Landfill'.

During the first year of the project, major construction continued on the 1,500 acre Orange County landfill site, which was the subject of the Demonstration Project. Consultants were employed to investigate the overall project area in terms of both surface topography and subsurface geology and hydrology. From these investigations, a master drainage plan was prepared which would govern the necessary excavations to permit the project area to be operated with certain portions dewatered below the level of refuse deposition. A future land use plan, as well as an operations plan, was prepared as the key to some assurance that maximum use could be made of the available land area. Within the project area a specific demonstration site was selected to serve as the initial site of refuse disposal for the Demonstration Project.

Prior to the beginning of landfill operations, an all-weather access road and the first components of the on-site circulatory road system were constructed. Subsequently, the initial phases of the on-site drainage network were completed in the area reserved for the landfill site. An outfall canal, connecting the site drainage network to the Little Econlockhatchee River, was then built. The construction of this canal completed the initial site improvements.

Following the construction of the site improvements, on-site facilities for the conduct of operations and maintenance were completed. These included a landfill site office, employee lounge, sanitary facilities, equipment maintenance shop, fuel storage area, transfer trailer washrack, scale and scale house, and a weather monitoring station. A well furnishing potable water was completed.

The model sanitary landfill environmental assessment reported herein is based on an investigation of the soils, geology, and hydrology of the site and on the water quality of the ground water at the landfill site and the surface water which leaves the site through an open drainage system. A literature search was a continuing part of the Demonstration Project. The

search helped to shape the work on environmental impact assessment and added to the engineering and planning criteria. The assessment was accomplished through a joint effort of biologists, chemists, and engineers at the Orange County Pollution Control Department, Florida Technological University and VTN INC.

During the project period, a well field of 38 shallow wells ranging from 10 to 30 feet in depth and four deep wells was installed and utilized to monitor physical, chemical and biological parameters. The initial six wells were sampled extensively during the first year to provide baseline data on ground water quality. Shallow wells were installed to detect any horizontal movement of contaminants. Well clusters containing two or three shallow wells of varying depths were constructed to examine vertical migration. The deep wells were built into the Floridan aquifer to detect any extensive vertical and horizontal migration of leachate.

Eleven surface water sampling stations were established along the reaches of the receiving stream and the canal system leading from the demonstration site. Seven sampling stations were located in the Little Econlockhatchee River, and the remaining four stations were in the landfill drainage system. Each station was monitored utilizing physical, chemical and biological parameters.

In the microbiological analyses, total counts of microorganisms were used to detect leachate movement into ground water or the movement of microorganisms as a result of heavy rainfall. Fecal coliform counts (or *Enterococcus* counts), *Samonella* enrichment, and *Staphylococcus* selection procedures were employed as attemps to detect introduction of pathogens into waters of the landfill area. Counts of both sulfur-oxidizing and sulfur-reducing bacteria and fungi were used as indicators of changes in native microbial populations due to leachate intrusion or effects of heavy rainfall.

In addition to the initial soils studies at the landfill site, periodic soils investigations were made during the project period. A weather station was established on the site for the determination of precipitation and temperature.

Landfill heavy operating equipment were evaluated as to their effectiveness, capabilities and problems encountered under both wet and dry cell construction and filling operations. Actual operating and maintenance costs for the equipment recorded over a one-year period were included in formulating an economic assessment of the "Demonstration Project." Additionally, landfill development capital improvement costs and all other operation and maintenance costs were used in the economic assessment. In order to provide an economic comparison base for the landfill operation, costs were developed for an incineration facility with equivalent solid waste disposal capacity.

The project was officially opened to selected commercial haulers on June 7, 1971. Full access to all began on October 4, 1971. The amount of waste disposed of at the site has increased, on the average, from 150 to 580 tons per day. The maximum amount of waste recorded for a single day was 1,114 tons. The total tonnage received from June 7, 1971 through October 1, 1971, was estimated at 15,000 (scales were not then available, and estimates were based on 59,875 cubic yards at 500 pounds per cubic yard). From October 1, 1971 through June 30, 1973, with scales in use, solid waste received into the landfill site totalled 265,047 tons. Thus, since start of operations through June 30, 1973, total tonnage received was 280,047.

During the life of the project, numerous persons visited the site. These ranged from high school and university students to environmental groups, Environmental Protection Agency officials, officials from many city and county governments, enforcement agencies, solid waste managers and interested citizens to mention a few.

On March 26 and 27, 1973, Orange County, Florida, in cooperation with the U.S. Environmental Protection Agency presented a seminar on Sanitary Landfilling in High Water Table Areas. The purpose of the seminar was to disseminate information on the Orange County, Florida demonstration and other projects concerned with solid waste disposal in high water table areas. Approximately 225 persons from many states attended the seminar.

Additionally, numerous technical papers on the project have been presented and others are being prepared for publication. A film on the project has also been made.

DISCUSSION AND CONCLUSIONS

During the project period of three years, the basic construction and operation plan formulated in the demonstration grant application was followed. Modifications to the plan were only made following a thorough evaluation of the findings and data available. Said changes consisted primarily of changes in cell design and construction, and in the frequency and scope of the environmental monitoring program.

It was originally anticipated that separate cells would need to be provided for the disposal of waste brought to the site by individual users and by franchised, municipal and county operators. This was thought to be needed to allow for the rapid mechanical unloading of vehicles running on a fixed time schedule and for the safety of individual users. To that effect, "demonstration cells" for the public were initially designed as shallow trenches without vehicular access to the bottom of the trench, and later as a progressive trench. Neither of these design concepts were satisfactory. In the first method there were operational problems associated with quantities of waste being deposited outside the trenches, and in the second, there was excessive runoff water accumulation in the low point of the trench at the working face. Mixing of all users in a single "demonstration cell" proved satisfactory. Thus the practice of constructing separate cells for public use was abandoned.

The original design called for transfer trailer "demonstration cells" to be built in two four-foot lifts. This design concept proved impractical due to the large size of some waste coming to the site. Demonstration cells were subsequently built with a single eight-foot lift.

Concerning "control cell" design, it was learned early in the project that filling to only the natural ground levels produced large quantities of excavated earth that needed to be moved from the "control cell" area. Due to the use of a dragline for excavation and the unavailability of dump trucks, the accumulated earth was stockpiled in a manner not suitable for easy removal. The design of "control cells" was modified to include two lifts. The first lift was built to within one foot of the original ground surface and the second was built four feet above the ground. This design proved satisfactory.

Even though major difficulties were not encountered in filling either demonstration or control cells, operational experience during the study period suggests the demonstration concept provides for a better overall filling operation in terms of access to the working face, litter control, maintenance of soil cover, damage to vehicles, overall appearance of the filling operation, and economics. The "control cell" concept, however, provides for maximum utilization of land areas since the trenches are excavated to a greater depth than in the "demonstration cell" concept.

The drainage system has proved to be effective in preventing flooding of the total project area during periods of intensified rainfall, and in lowering the water table in the "demonstration cell" area during normal rainfall conditions. However, intense rains have caused localized cell floodings. Experiments with temporary pumping indicate that this is the best solution to cell flooding brought about by heavy rains.

Data collected during the first year of the project provided baseline information on the quality of the ground and surface waters associated with the project. The environmental assessment of the landfill was made in reference to the baseline information. In this regard, it is concluded that the drainage improvements minimized the releasing of leachates, but did not prevent changes in the water quality of the upper ground waters. Changes in ground water were found in samples from one well below a demonstration cell, one well below a control cell and four wells immediately adjacent to control cells. This contamination was expressed within a profile 5 to 20 feet below ground surface. Chemical and biological data do not indicate any extensive verticle movement beyond a 20-foot depth. Studies also indicate that horizontal movement of waterborne contaminants from the "control cell" area to the monitoring well was at a rate of approximately 3 feet per month. In the "demonstration cell" area migration to the drainage canals and oxidation pond was not observed.

Because of this experience and the findings of the soil and geology study of the site, burying the waste to insure dry conditions might be reconsidered at this site. If, because of geologic and hydrologic conditions, migration of leachate can be confined within the property boundaries of a site, a case might be made for permitting landfilling under wet conditions. The landfill would then operate in a manner similar to a digester. Drainage would only be needed to sufficiently insure filling operations in wet weather.

From the environmental assessment at the Orange County, Florida demonstration landfill, it appears that either a dry or a wet condition might be environmentally satisfactory under geologic and hydrologic conditions which promote leachate containment. The wet case should not be arbitrarily discounted.

The fact that distribution of leachate is occurring very slowly is advantageous to the landfill. It will have two effects. First, there will be a longer time for decomposition of organics, hence the amount of organics passing from the landfill should be reduced. Secondly, the concentration in the outfall water should be correspondingly less. Both of these are protective to the environment.

Site selection, planning, and engineering a landfill should consider all possible alternatives, with development to insure the minimum environmental impact. In this regard, plans were discussed to recycle oxidation pond waters if release of pollutants occurred and the pond was not effective in reducing contaminant concentrations.

Pollutants were not detected in the oxidation pond during the period for which data are reported and recycle was not required. Even though it is anticipated that the oxidation pond will be effective in treating water contaminated by a very slow release of pollutants, the effectiveness of such pond was not tested during this period.

A sudden and large release to surface waters of contaminated ground waters would have an adverse environmental impact on the receiving waters. The oxidation pond would not be able to adjust rapidly to such shock loading. It is therefore recommended that drainage channels excavated between cells for the initial purpose of lowering the water table be maintained for the purpose of storm water runoff. Excavation of channels near solid waste filled areas could cause direct discharge of contaminated ground waters to surface waters and shock loading of the treatment facilities.

Concerning the water quality monitoring program, it is recommended that ground water sampling wells be installed at landfill sites. The depth, location and numbers of wells should be established based on the recommendations of a ground water hydrologist. The purpose of the sampling wells is to verify the effectiveness of the soil in containing and treating leachates, and in providing an early indication of potential pollution problems. The well field should also be established based on an understanding of the presence of other pollution sources, water resources and water use in the area. Wells might need to be installed outside the landfill property boundaries.

For the research purposes of this demonstration program, the well system functioned satisfactorily. However, it is recognized that the extensive program followed in this project would be impractical and unwarranted at other landfills. The basic well design used in the project is recommended, but the well point length should be determined based on the objectives of the sampling program–general monitoring vs. special studies. The 10-foot well point used in some of the wells does not provide for specific determination of the depth of leachate migration.

The sampling frequency should be a function of the rate of ground water movement as determined in the ground water hydrology studies. Initially, wells should be sampled frequently until representative baseline data are obtained. Following initiation of landfilling operations, the wells near the filling activities should be sampled at least four times a year, and wells distant from the landfill could be sampled two times a year until changes in water quality are detected. At such time, the frequency of sampling should be increased.

The following parameters should be part of the analytical program: chlorides, Kjeldahl and nitrate nitrogen, pH, RpH (reserve), conductivity, chemical oxygen demand and total hardness. Additional analyses that would be of value but that would not be necessary for a minimum program are: iron, aluminum, potassium, sodium and total carbon.

If an outlet for ground water to enter the surface water exists, a monitoring program containing both biotic and abiotic parameters should be considered. Biotic parameters are of value in showing contamination that might go undetected in a grab sample taken for physical and chemical water quality analysis. Surface waters are subject to considerable seasonal variations necessitating a good understanding of the biological system involved. In the beginning, sampling frequency should be directed toward obtaining that understanding. Parameters monitored should include those recommended for ground waters in addition to dissolved oxygen, biochemical oxygen demand, nitrate and phosphate. Biological parameters utilized in the monitoring program should include the plankton and macroinvertebrate communities.

The total Model Landfill expenditure during FY 1971-1972 (October 1, 1971 through September 30, 1972) to process 138,461 tons of refuse showed a cost/ton ratio of $3.33 for the period. On the basis of FY 1972-1973 budgeting and expected tonnages, this cost is expected to decrease to $2.31 per ton. This decrease can be attributed to stability of operating techniques, improvement in equipment maintenance, and growing personnel experience in landfill procedures. Increased tonnages expected as a result of closing the County's Porter Landfill during 1973 may serve to further reduce the ratio to approximately $1.79 per ton. Continued procedural refinements and techniques of operation should eventually stabilize total costs in the vicinity of $1.50/ton. The cost of constructing "demonstration cells" was less than the cost of constructing "control cells". Thus, there was an economical advantage to filling in dewatered areas.

In summary, it is concluded that a landfill can be constructed in a high ground water table area provided that it is located, planned and engineered properly. Adverse environmental impacts can be prevented and minimized. The added cost of site improvements and dry bottom cell construction is acceptable in relation to costs of alternate methods of disposal such as incineration and landfilling in non-dewatered areas.

It is recommended that in a high water table area, site selection, planning and design be done only after a complete understanding of ground water movement in the area has been reached. A landfill in a high ground water area can only be built successfully if the generated leachate can be contained within the property and controlled so as not to pollute usable ground and/or surface waters. Under these conditions of trench type filling it is difficult and expensive to construct a leachate collection system. Therefore, leachate containment is a function of the geology and ground water hydrology. Under optimum geology and ground water hydrology conditions, it is possible to fill directly into the ground water with a minimum of adverse environmental impact. A decision to proceed along this concept should carefully be evaluated in relationship to water pollution, aesthetics, public relations, mosquito control, vector control, and safety.

It is recommended that a water quality monitoring program be a continuing program extending beyond the filling operation period. As such, the well field at the demonstration site in Orange County, Florida should be preserved for further investigations throughout the life of the landfill operation and thereafter. Since leachate migration is very slow, studies extending the current work should be continued to fully evaluate the leachate migration pattern, and effectiveness of the oxidation pond for treating leachate-contaminated waters.

INTRODUCTION

Community solid waste disposal problems over the years of civilization have been considered as neither acute nor dramatic, but simply as minor irritations of urban living. More recently, and in response to a highly increased standard of living and a commensurate increase in solid waste generation, there is the recognition of a major problem. And there is the further recognition that improper solid waste disposal can lead to a general degradation of the environment, waste natural land resources, and is a clear threat to health through the potential pollution of air and water as well as the harborage of vectors involved in disease transmission. Correction of existing and emergent problems will require innovative solutions.

The problems associated with solid waste disposal are particularly acute in areas such as the southeastern coastal region of the United States. In this region, high water table conditions prevail, and elevations are fairly uniform with a minimum of rugged terrain suitable for sanitary landfill construction. Consequently, it is common to find solid waste being buried below the naturally occurring ground water table with varying degrees of ground water protection. Varying deposition practices abound, including the depositing of solid waste on the ground surface, directly into the ground water, and into temporarily dewatered working areas. In contrast, the Florida Department of Health and Rehabilitative Services, Division of Health, as governed by Chapter 10D-12, Florida Statutes, in regulating the disposal of garbage and rubbish, require--when working in wet areas--that trenches or pits be kept dewatered during operating periods. Additionally, many provisions of Chapter 403, Florida Statutes for Environmental Control, relating to pollution of surface and ground waters, are being interpreted to include the regulation of land disposal of solid waste. These environmental controls have particular application in Central Florida, because of the potential pollution of ground waters due to improper land disposal of solid waste.

The relatively flat topography of Central Florida in combination with a very high ground water table makes efficient construction of sanitary landfills a particularly challenging problem. In addition, a recreation oriented population, with a deep concern for the maximum protection of the environment, suggests it is imperative that all possible control will be exercised in the construction and operation of a sanitary landfill in such areas. Orange County officials encountered a very particular problem. While attempting to gather all available data for the proper design of solid waste disposal facilities, they soon recognized the need for further development of sanitary landfill construction technology for high water table areas. Specifically, information was needed on cell design, equipment selection, operating procedures, environmental protection, and costs for construction and operation. In an attempt to develop information not then available in current literature, the Board of County Commissioners for Orange County made application to the Bureau of Solid Waste Management, U. S. Public Health Service* for a Demonstration Grant titled,

*After Federal reorganization, the funding agency is now the Office of Solid Waste Management Programs, U. S. Environmental Protection Agency.

"Effective Use of High Water Table Areas for Sanitary Landfill". The grant was approved and designated as Project S-802283 (formerly G06-EC-00309). This is the final report on that Demonstration Project.

Recommendations covering site selection for sanitary landfill operations suggest all filling be done where the filling operation will be above the water table. However, this is virtually impossible in normal operation over a long period of time in the greater part of Florida without auxiliary drainage and perpetual pumping. Otherwise, it must be assumed two things will happen. First, there may be flooding at irregular times from storms and hurricanes. Secondly, the high rainfall prevalent throughout Florida will eventually bring the fill to field capacity with rapid decomposition and with subsequent rains causing leachate. Both conditions will prompt the passage of material to the surrounding ground water and/or surface water. These conditions also will result in rapid decomposition of the refuse once it becomes wet. The process is inevitable, and unless controlled, the potential for contamination of ground water resources is increased. Therefore, the objectives covering the Demonstration Project recognize this need for process control. The broad objectives are

. . . the demonstration that properly engineered drainage improvements--combined with refuse cell construction which will prevent or minimize horizontal and vertical passage of water through decomposing waste--will prevent harmful degradation of both surface and ground waters within the project area

. . . the demonstration that the added cost of site improvements and cell construction in a high water table area to protect water resources is acceptable in relation to costs of alternate available methods such as incineration

. . . the demonstration that sanitary landfill construction equipment, properly selected to operate in relatively wet areas, is essential to the economic efficiency of this type of project

. . . the establishment of a practical, long term, well publicized example of sanitary landfill construction in 'wet' land which can serve as valuable guidance for similar projects in other areas of the nation.

The specific primary objectives of the Demonstration Project were

. . . the development of design criteria and operating techniques for sanitary landfill construction in high ground water areas which take into full consideration the environmental impact and the cost of construction and operation

. . . the demonstration of feasibility and cost benefits of properly designed and operated landfills on sites in high ground water areas

. . . a well publicized example of landfill construction in high ground water areas.

As secondary objectives, the Demonstration Project

. . . investigated the physical, chemical, and bacteriological characteristics of the aqueous environment in the refuse cells

. . . assisted in strengthening the Environmental Sciences curriculum at Florida Technological University as a natural outgrowth of faculty and student participation in the conduct of the Demonstration Project.

In the reach for the project objectives, two basic approaches to landfilling were established, namely: (1) landfilling in non-dewatered trenches, and (2) landfilling in trenches having dry bottoms due to the lowering of the water table. The first condition cells are referred to as "control cells" since these would be typical of a non-ground water protection landfill operation. The second condition cells, or dry cells, are referred to as "demonstration cells", since the demonstration of a maximum resource protection landfilling operation is the specific purpose of the Demonstration Project. For the purpose of this project, the term "cell" refers to a trench consisting of daily covered solid waste depositions commonly referred to as daily cells.

The conduct of the three-year Demonstration Project involved a year of initial preparation and two years of actual operation. All refuse disposed of during the period covering the Demonstration Project was landfilled in the "demonstration site", a portion of the 1,500 acre landfill site. Because of this distinction, all references to disposal areas and operations found within this report, unless otherwise noted or specified, refer to the "Demonstration Project" or "demonstration site".

Since Florida statutes do not authorize landfilling in non-dewatered conditions, specific approval was solicited and obtained from the State to construct and operate the "control cell" so as to permit comparative evaluations of dewatered and non-dewatered cell operations for the period of the grant.

SITE SELECTION

The proposed Demonstration Project required a particular area. Accordingly, a number of factors had to be considered during the selection process. These factors offered a variety of limitations and restrictions. Working within the frame of these limitations and restrictions, a number of possible landfill sites were evaluated. Following this evaluation, an area was chosen for the Demonstration Project Area within the acreage purchased for the sanitary landfill operation.

Preliminary Considerations

Orange County, located in rapidly growing Central Florida, extends some 48 miles from east to west with a maximum north-south width of 30 miles (see Figure 1). It is bounded on the north by Seminole and Lake Counties, on the west by Lake County, and on the south by Osceola County. The eastern boundary is the St. Johns River which separates Orange from Brevard County.

According to the 1970 Census of Population, the population count for Orange County was 344,311, of which approximately one-third resided in the City of Orlando. Major on-going and planned developments within the county, such as Walt Disney World, are having a major impact upon the overall development of the area. Consequently, it is anticipated the present population will double in number during the next 15 to 20 year period. Solid waste tonnages generated are anticipated to increase accordingly to an estimated 458,440 tons per year by 1990 (see Figure 2).

There was evidence of serious concern by Orange County officials regarding the proper management of solid waste. Various in-house studies have been prepared during the last decade. The Orange County Planning Department, in April 1967, issued a report titled *Proposed Solid Waste Disposal Program for Orange County, Florida* This report was the proposed implementation program covering recommendations made in an earlier in-house report entitled *Solid Waste Disposal Study*. It provided the design of a program for the efficient and sanitary disposal of solid waste within Orange County.

The basic overall recommendations of the completed studies suggested the closing of existing dumps, the abandonment of small landfill operations, and the consolidation of operations in an engineered system, including a major landfill and a network of transfer stations. It was further recommended that the site selected for the central landfill operation have enough capacity to serve through the year 1990. It should, ideally, be located in an area where other vacant land would be available for expansion.

Even though Orange County does not provide waste collection services, the overall cost to the residents of the area for the handling of solid waste was a primary concern. Thus, a system of transfer stations sufficient to serve a widely scattered populace was recommended.

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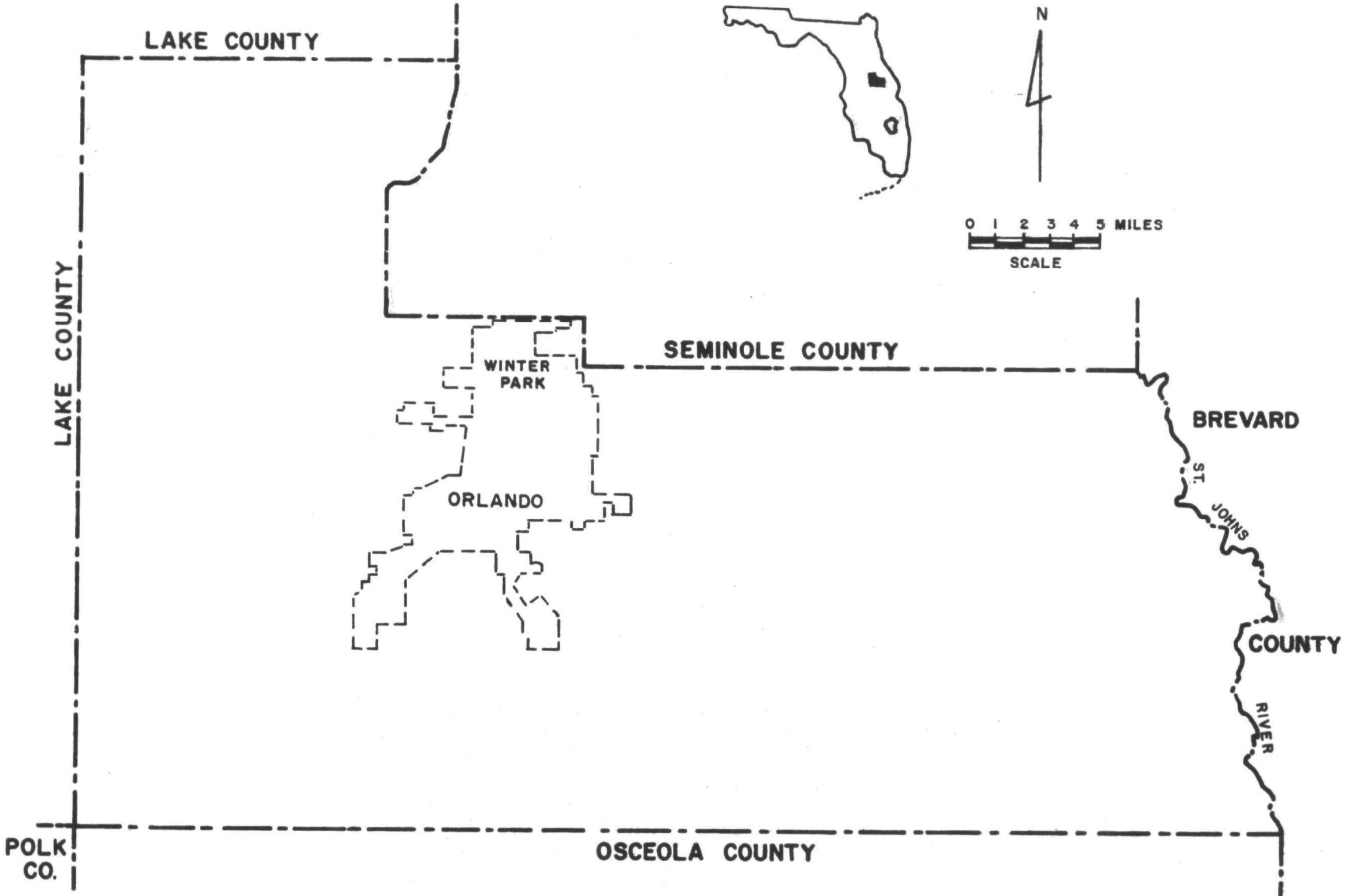

FIGURE I. Vicinity Map of Orange County, Florida.

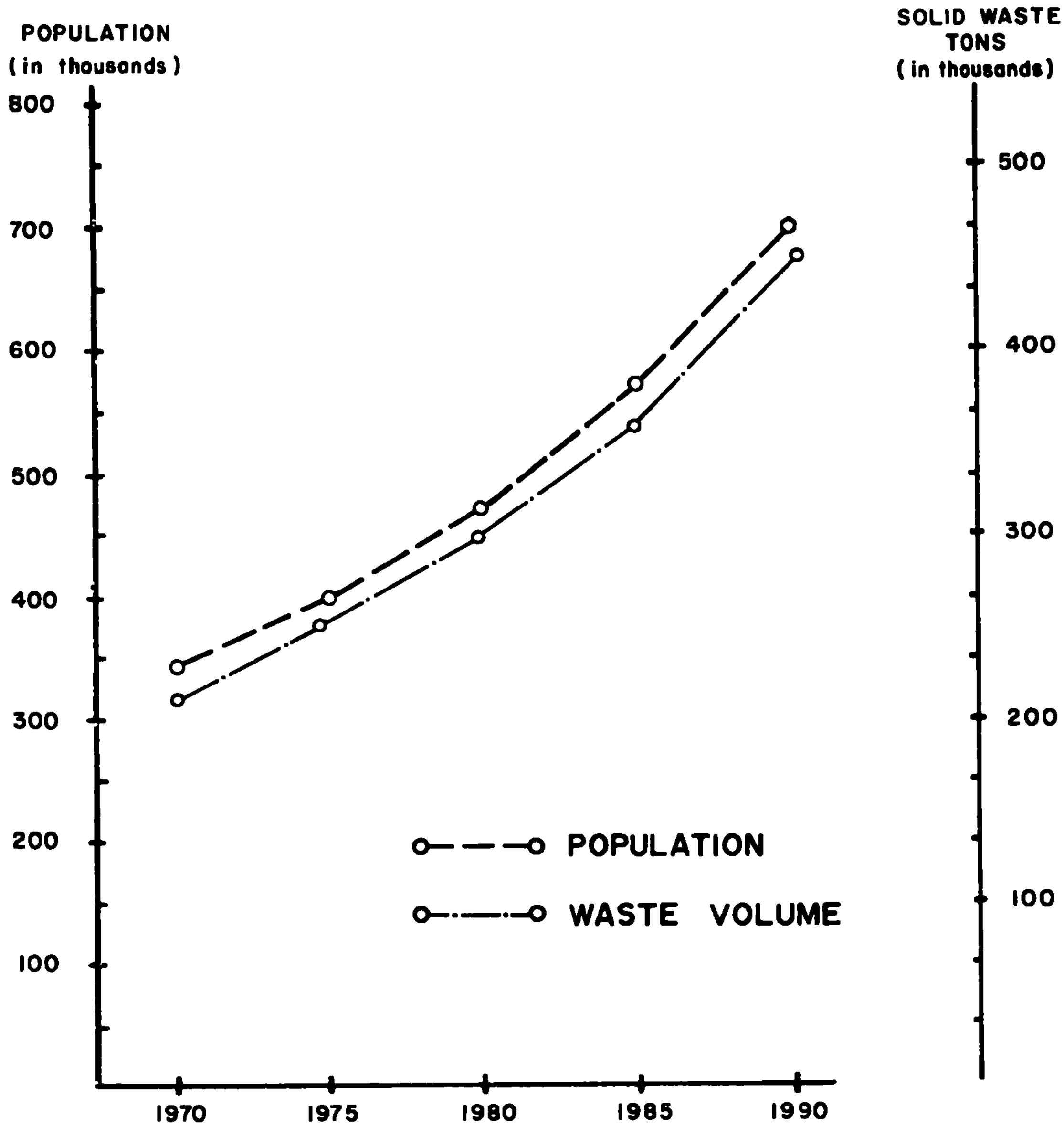

FIGURE 2. Population & Solid Waste Generation Projection, Orange County, Florida.

SOURCE : U.S. Bureau of the Census, 1970 Census.

Population Forecasts, East Central Florida Regional Planning Council.

Fortunately, a modern road system existed throughout Orange County. This road system made the transportation of wastes from transfer stations to a centralized landfill operation-a ready possibility.

The then existing solid waste disposal system servicing Orange County included four dumps, one landfill, one transfer station and two incinerators (Figure 3). Some of these facilities were not under the jurisdiction of the Orange County Board of County Commissioners. The proposed system, now under the program of implementation, is shown in Figure 4. The site shown in Figure 5 was chosen as the central sanitary landfill and as the demonstration site.

Site Considerations

The more important considerations were those concerned with geographical location, climatology, geology and hydrology. The more important aspects of each of these considerations are discussed in the following paragraphs.

Geographical Location. The site selected for the Demonstration Project is in central Orange County some ten miles southeast of Orlando. It covers an area of 1,500 acres. The covered area is considered as marginal flat land with a high water table. Pine and palmetto growth and native grasses are the predominant vegetation. There are some swamp areas, which include cypress stands as well as mixtures of ordinary trees and shrubs (Figure 6). Ground elevations range from approximately 78 to 92 feet above mean sea level (MSL), as shown in Figure 7.

The overall relationship of the road system to available lands was important to area selection. The existence of these roadways would minimize access right-of-way acquisitions.

Electric power and telephone services were available to all sections of Orange County. Therefore, availability of these services to any area selected could be assumed. It was assumed further that potable water would be available. Where a municipal source would not be available, local ground water resources were readily developable.

Climatology. The climate of Orange County is considered subtropical. Temperatures are greatly modified by winds blowing across the area from either the Gulf of Mexico or the Atlantic Ocean. The summers are warm and humid. Thunderstorms occur almost every afternoon during the summer months. Winters are short and mild with many days of bright sun and little precipitation. However, short cold spells can be expected occasionally during the winter months. The average annual temperature is 72.5 F, with an average winter temperature of 62.6 F and an average of 81.8 for the summer months. The estimated rate of evapotranspiration in the Demonstration Project area is about equal to the average annual rainfall of 50 to 51 inches.

The nearest complete weather station is located at Herndon Airport, some eight miles from the project area. Due to wind variations in local weather patterns, it would be erroneous to utilize Herndon Airport weather data as applicable to the project area, especially rainfall data.

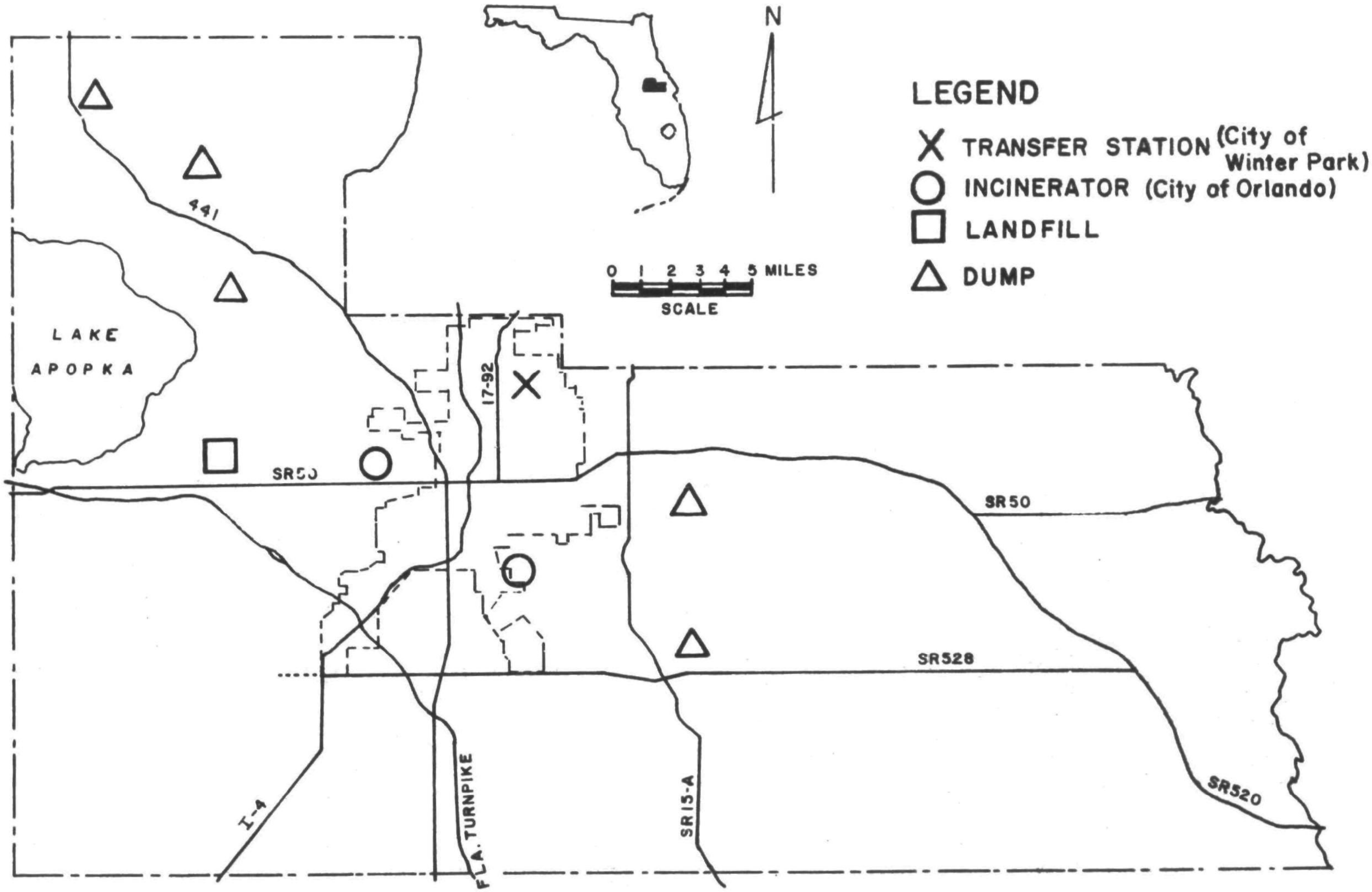

FIGURE 3. Solid Waste Disposal System, Orange County, Florida as of Mid 1970.

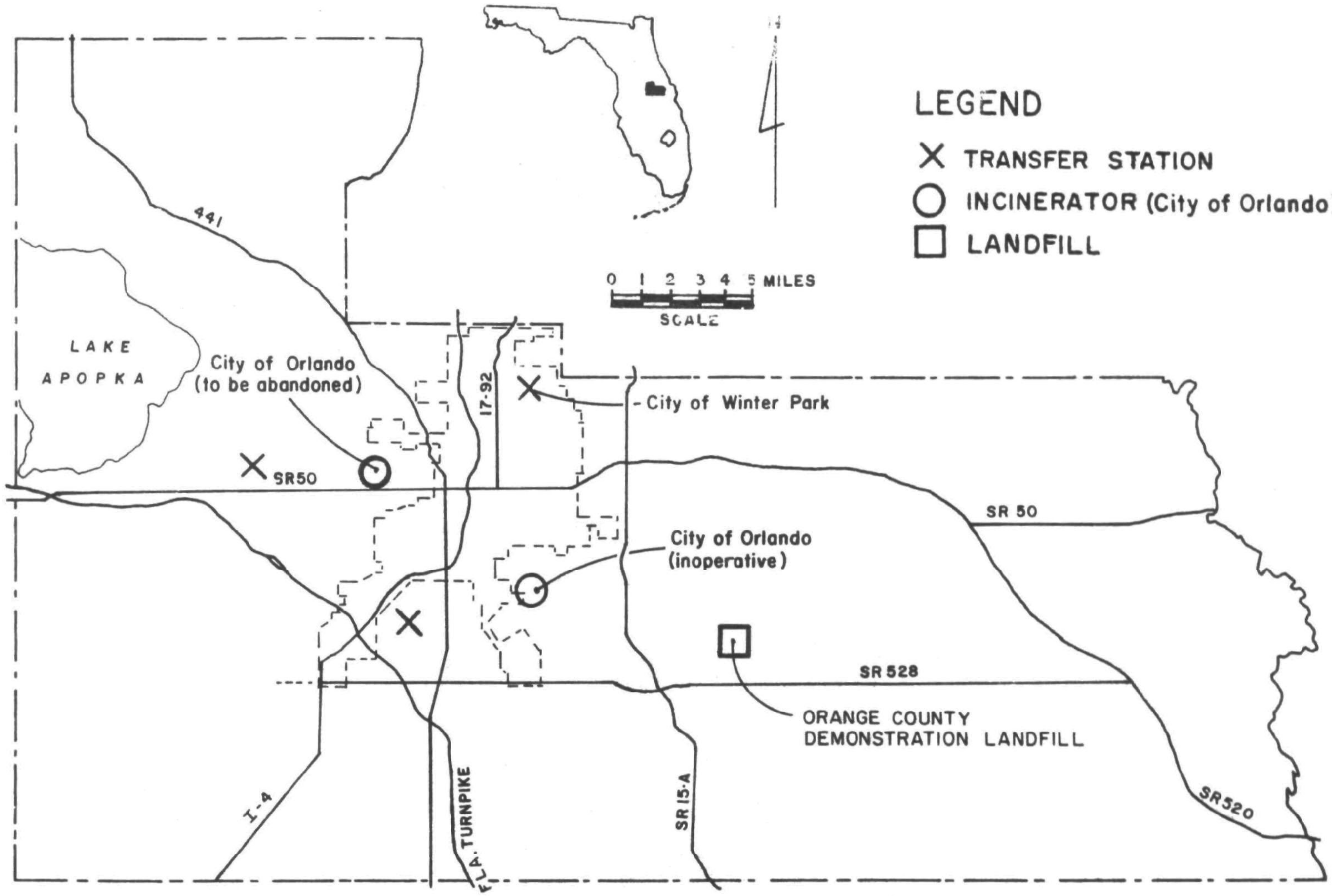

FIGURE 4. Proposed Solid Waste Disposal System, Orange County, Florida.

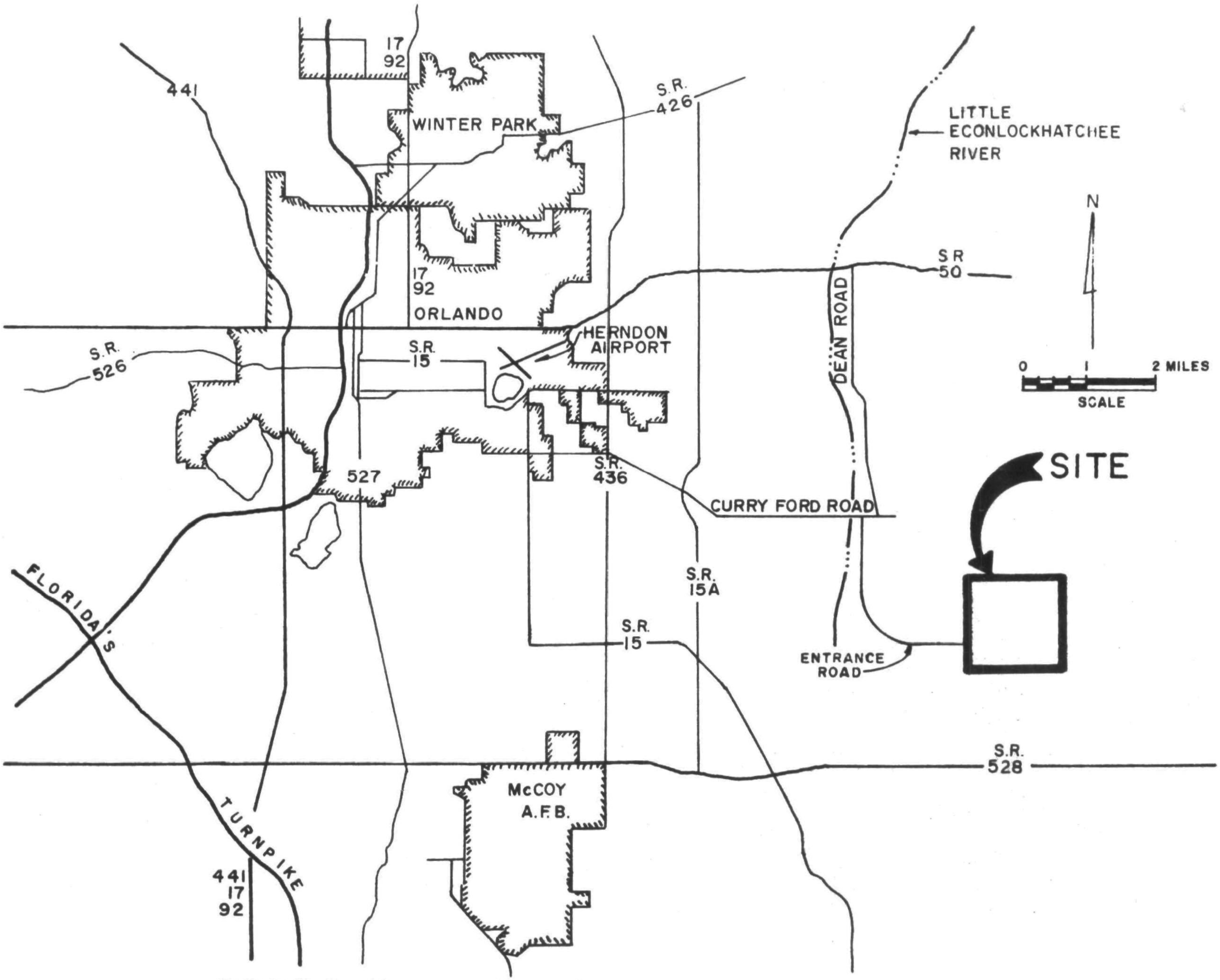

FIGURE 5. Vicinity Map of the Orange County Sanitary Landfill.

FIGURE 6 Cypress Stand in Swampy Area of Landfill Site Prior to Drainage Improvements.

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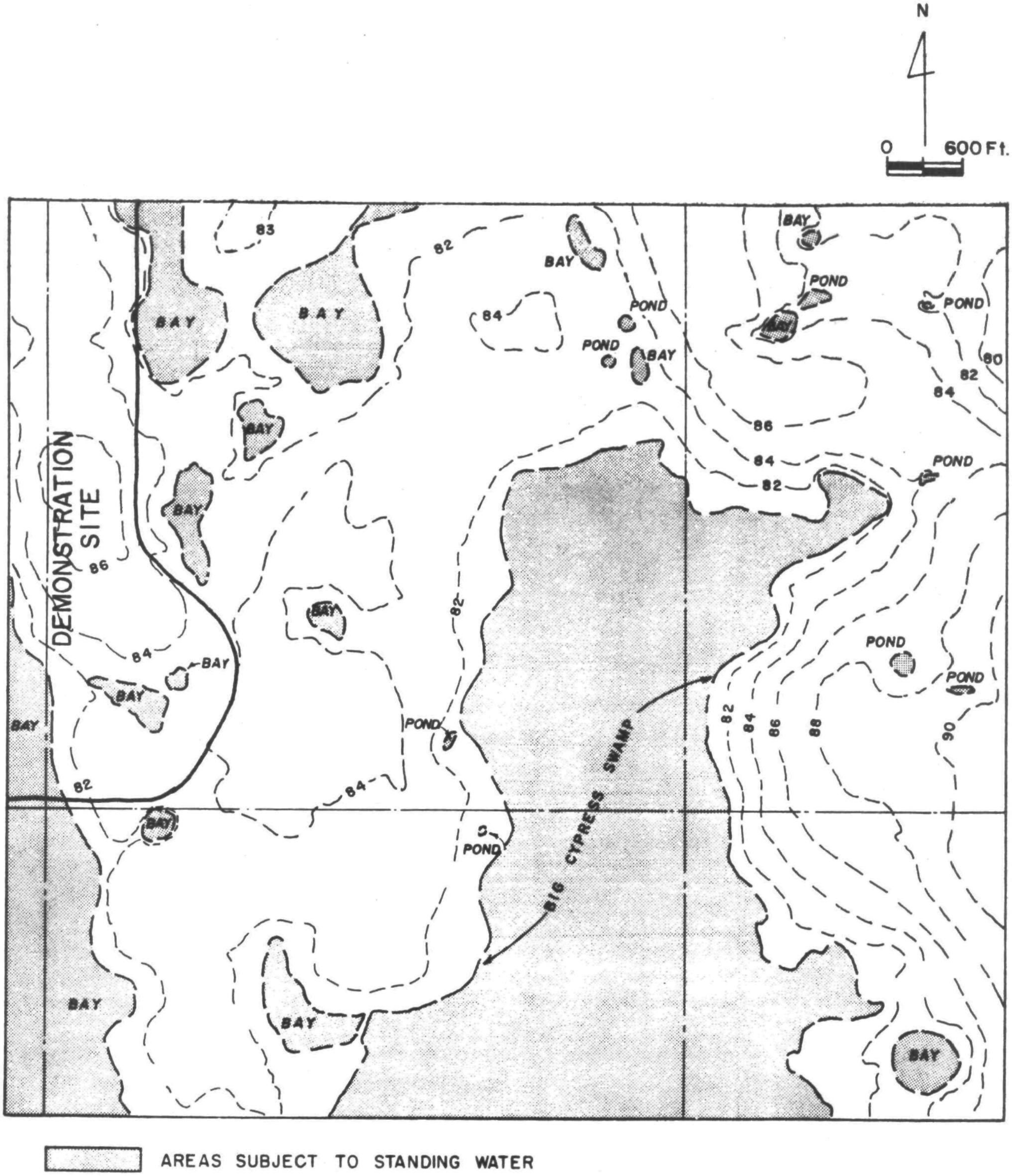

FIGURE 7 Topographic Map of Landfill Site, Orange County, Florida.

Therefore, in view of the potential importance of the relationship between climatological conditions and the various parameters being monitored at the demonstration site, a weather station was installed. The installed facilities include a Belford tipping bucket rain gauge with recorder and counter and a Temp-scribe temperature recorder.

Geology. Peninsular Florida is underlain mostly by fragmental and marine limestone, sandstone, and shale formations which reach a known cumulative thickness of more than 18,000 feet. Few deep well developments in Florida have penetrated crystalline rocks such as granite and hornblende diorite. Such rocks, when found, are believed to be either Pre-Cambrian or Paleozoic intrusives. The core of the Florida plateau is Pre-Cambrian.

A layer of Pleistocene sand with an estimated thickness of 25 to 35 feet is found at the demonstration site. Plio-Miocene deposits of land pebble phosphate, shark teeth, Manatee rib fragments, shell fragments, sand, and sandy clay underlay the Pleistocene sand. The thickness of the phosphatic and shell layer ranges from approximately four to eight feet. An impermeable layer of clay is found beneath the phosphatic zone. Organic or muck deposits of varying depths are also found at the demonstration site. Sinks, developed through solution process affecting the limerock, are common in much of Florida. However, sinks have not been found in the project area.

Hydrology. Rain water, when it becomes ground water, percolates downward until it reaches an impervious strata, then moves laterally toward an outlet. Sometimes the movement is in permeable rock between impermeable layers. The water bearing rock formation is known as an aquifer and the water above the impermeable cap is known as free ground water.

Florida has one of the great aquifers of the world. This aquifer discharges billions of gallons of water each day to the surface through springs and flowing wells. The piezometric water level at the project site is approximately 40 feet above MSL. Due to the relatively minor changes in elevation at the landfill site, water movement in both the horizontal and vertical directions was non-existent. Variations in the water level are due to rainfall, evaporation and transpiration. Prior to the construction of drainage improvements at the demonstration site, the project area had a history of temporary flooding. During hurricane occurrences, or periods of extreme rainfall, flooding may be a problem. But, inundation of the project area as a whole is not expected, nor did it occur during the Hurricane Agnes passage in mid-June 1972. Procedures to alleviate cell floodings are discussed under the "Landfill Operations" section following.

The movement of the topmost ground waters is affected mostly by surface soil deposits and their geological deposition. In a layered system such as is found at the demonstration site, the lateral permeability is the governing factor in ground water movement. And for the most part, three surface soils are found throughout the entire site. These consist of: (1) a light brown fine sand, averaging 14 to 30 inches thick, overlying (2) a brown fine sand locally known as "hardpan", approximately 2 to 6 feet thick, and (3) a layer immediately below the "hardpan", approximately 24 feet thick, a light brown fine sand with slightly more silt in its composition than found in the surface deposits. The movement of the ground water is restricted by the occurrences of the "hardpan". For while the lateral permeability of the surface soils is estimated to be between 700 and 800 feet per month, the lateral permeability of the "hardpan" is restricted (40-100 feet per month).[2] Accordingly, it can be assumed the surface ground water movement will be within the first soil layer and not in the "hardpan".

For soils similar to these found at the demonstration site, the normal ground water hydraulic gradient is 150 feet horizontal to 1 foot vertical. This is considered to be the minimum gradient needed for water movement within the first soil layer. However, lateral movement of water at the demonstration site could be induced by the construction of drainage channels below the water table, thereby artificially increasing the gradient.

Surface and ground water elevations of the entire project area were determined in November 1970. These are shown in Figure 8. The maximum water elevation recorded then was 86.3 feet above MSL. Respecting the demonstration site, the ground water elevations were approximately 79 feet above MSL. Throughout most of the Project area, the naturally occurring ground water table is found within five to eight feet below the existing ground elevations.

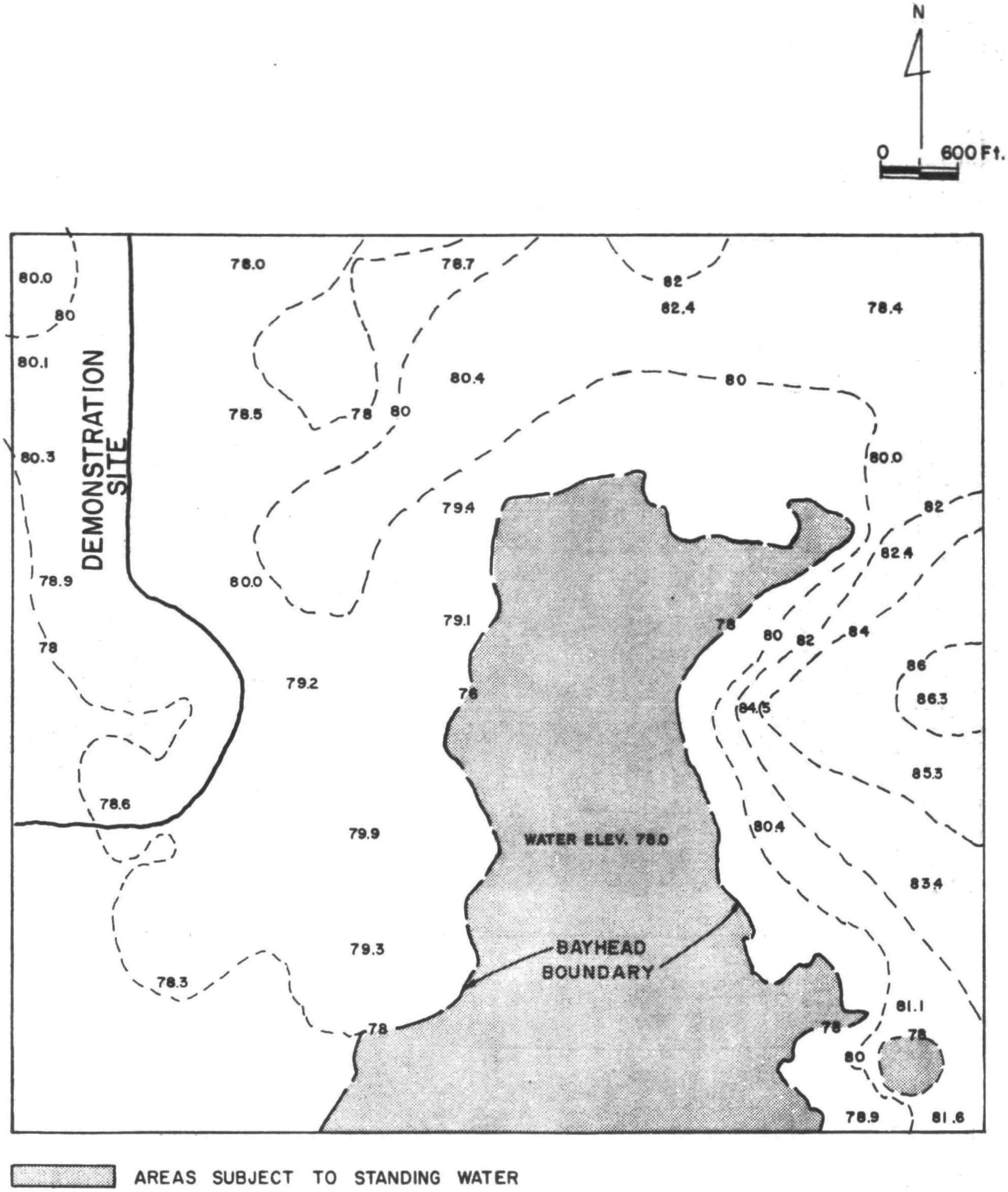

FIGURE 8 Ground Water Map of Landfill Site, Orange County, Florida.

THE SANITARY LANDFILL

The landfill operation was opened on June 7, 1971, on a limited basis, to franchised residential refuse collectors. Difficulties in obtaining equipment adequate to handle the anticipated tonnage of waste generated in Orange County prevented the start of full operations at the demonstration site at that time. The landfill has been in full operation since October 4, 1971.

Site Development

The development of landfill operations required the construction of both on-site and off-site roads and drainage improvements, as well as on-site facilities. The off-site improvements discussed in the following paragraphs refer to those indispensable for operation of the landfill, i.e., the access road to the project area connecting to the closest existing improved road, and the outfall canal connecting the demonstration site to the nearest major drainage channel. The on-site improvements, in turn, refer to those made within the project boundaries.

Access Road. A 3.1-mile access road from Curry Ford Road to the project area was built as an off-site improvement. This facility includes two 12-foot lanes. It passes through an area of heavy organic deposits or muck. Accordingly, 200 feet of 5 to 8-feet muck deposits had to be excavated and the excavation backfilled with suitable road material. An important phase of the access road construction project was the landscaping of the entrance (Figure 9) and the erection of fences and gates (Figure 10).

Circulation Roads. Prior to Project area improvements, the alignment for a system of circulation roads servicing the 1,500 acre site was established. The system was designed to insure adequate vehicular circulation commensurate with the land use proposals established for the project area (Figure 11, Proposed Use Master Plan), and to provide access to the disposal areas during landfill operations. There will be no landfilling of disposal waste within the established road rights-of-way. Construction of appropriate roads will be similar to that established for the access road. Approximately 2,500 feet of circulation roads have been completed with about 1.5 miles of extensions under construction.

Outfall Canal. Drainage has been a major consideration in the construction of the various project area improvements. This consideration was in response to the high ground water table conditions found throughout the project area and the existence of a series of swamps within the landfill site. An outfall canal (Figure 12) - about 2.7 miles long - was excavated from the landfill site to the banks of the Little Econlockhatchee River (Figure 13). This canal was designed to provide rainfall drainage sufficient to accommodate a twenty-five year design storm for the entire 1,500 acre landfill site. This corresponds to an accumulative, four-day rainfall of approximately ten inches. The overall design dimensions for the canal provided a 9-foot depth, a 30-foot bottom width, and side slopes of 2 to 1.

While construction of the outfall canal was under way, it became apparent that excavation in two phases was desirable in order to provide some drainage and to permit an initial

FIGURE 9. Entrance Landscaping and Sign, Orange County Sanitary Landfill.

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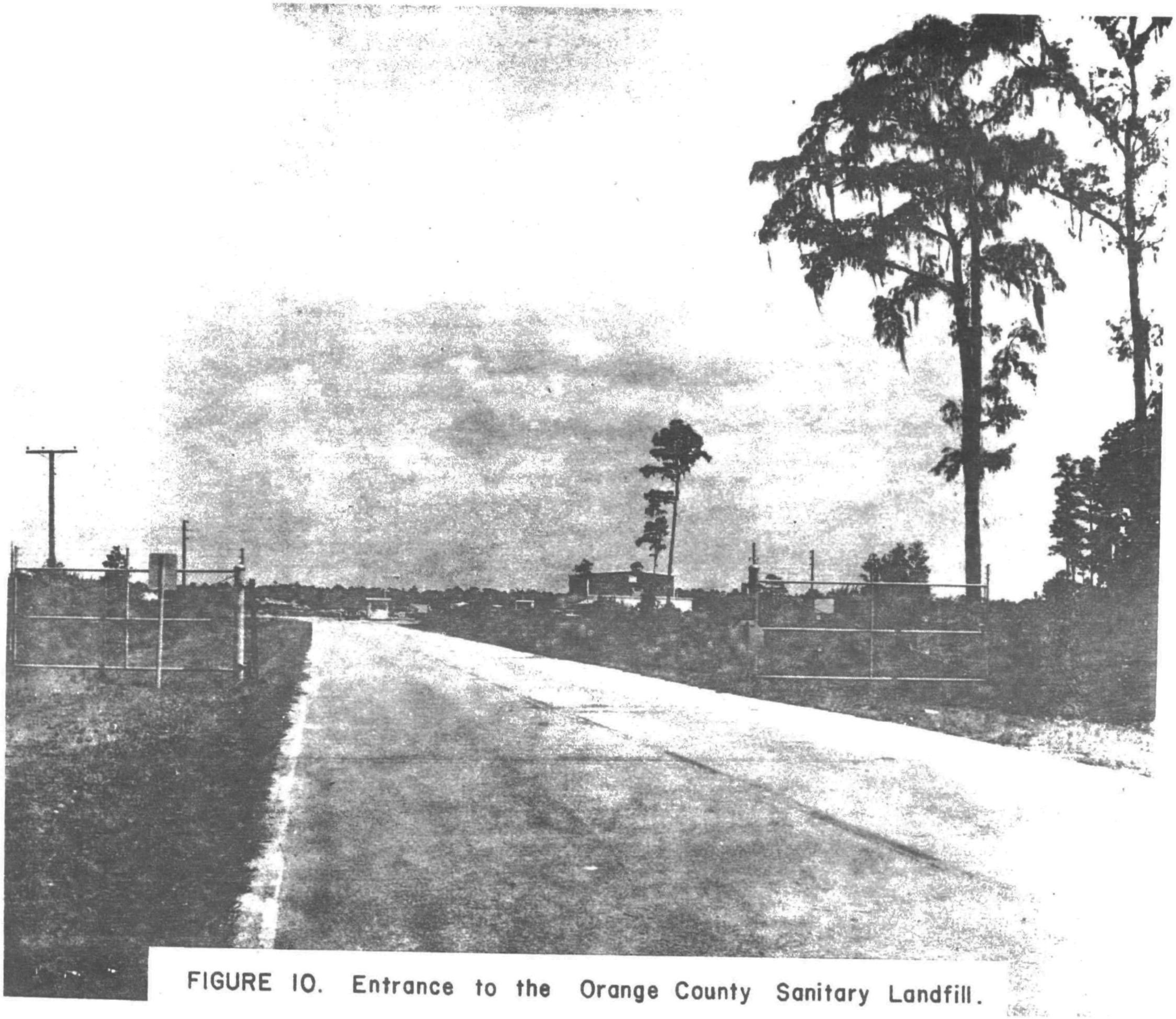

FIGURE 10. Entrance to the Orange County Sanitary Landfill.

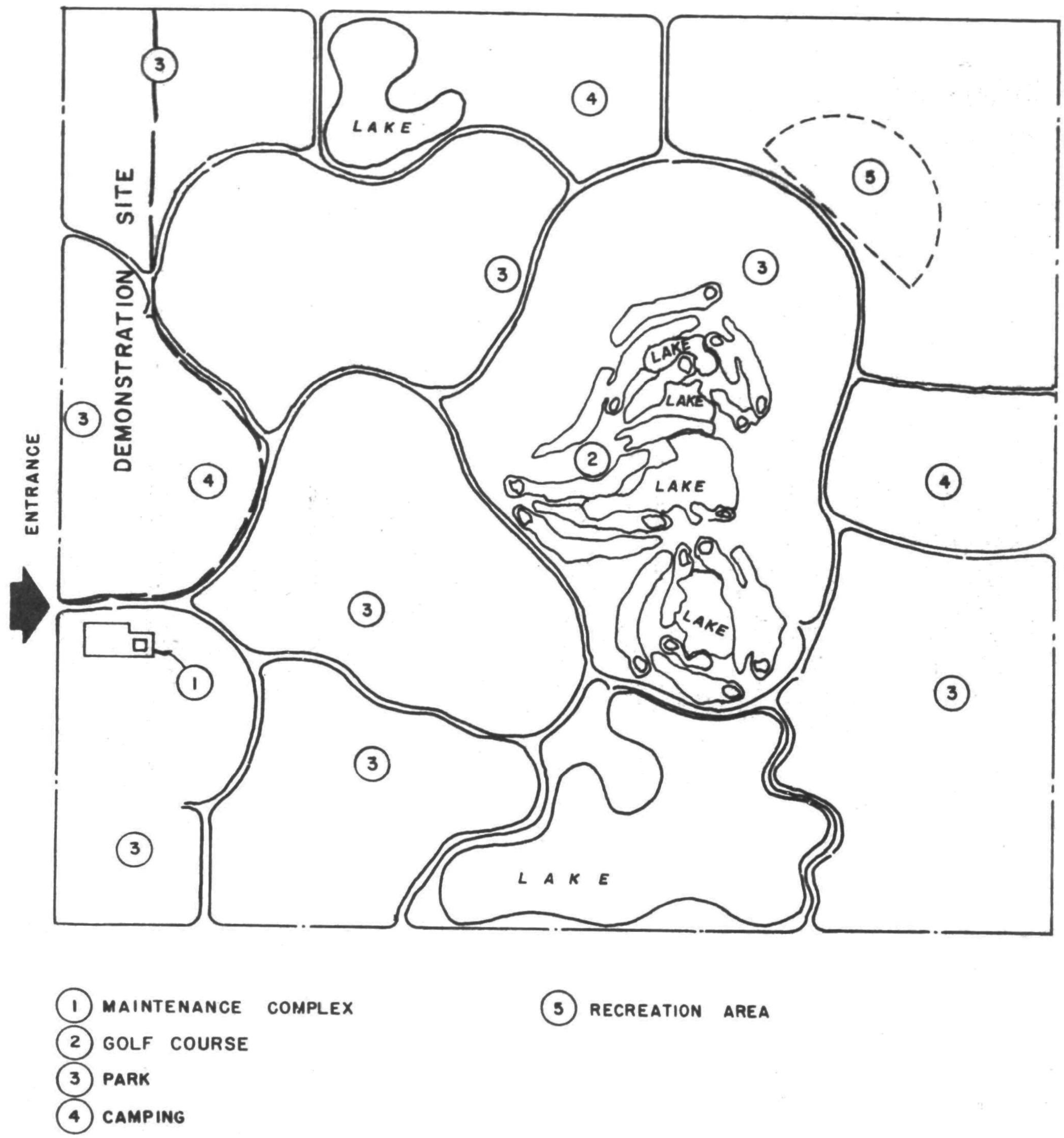

FIGURE 11. Proposed Future Use Master Plan, Orange County Landfill Site

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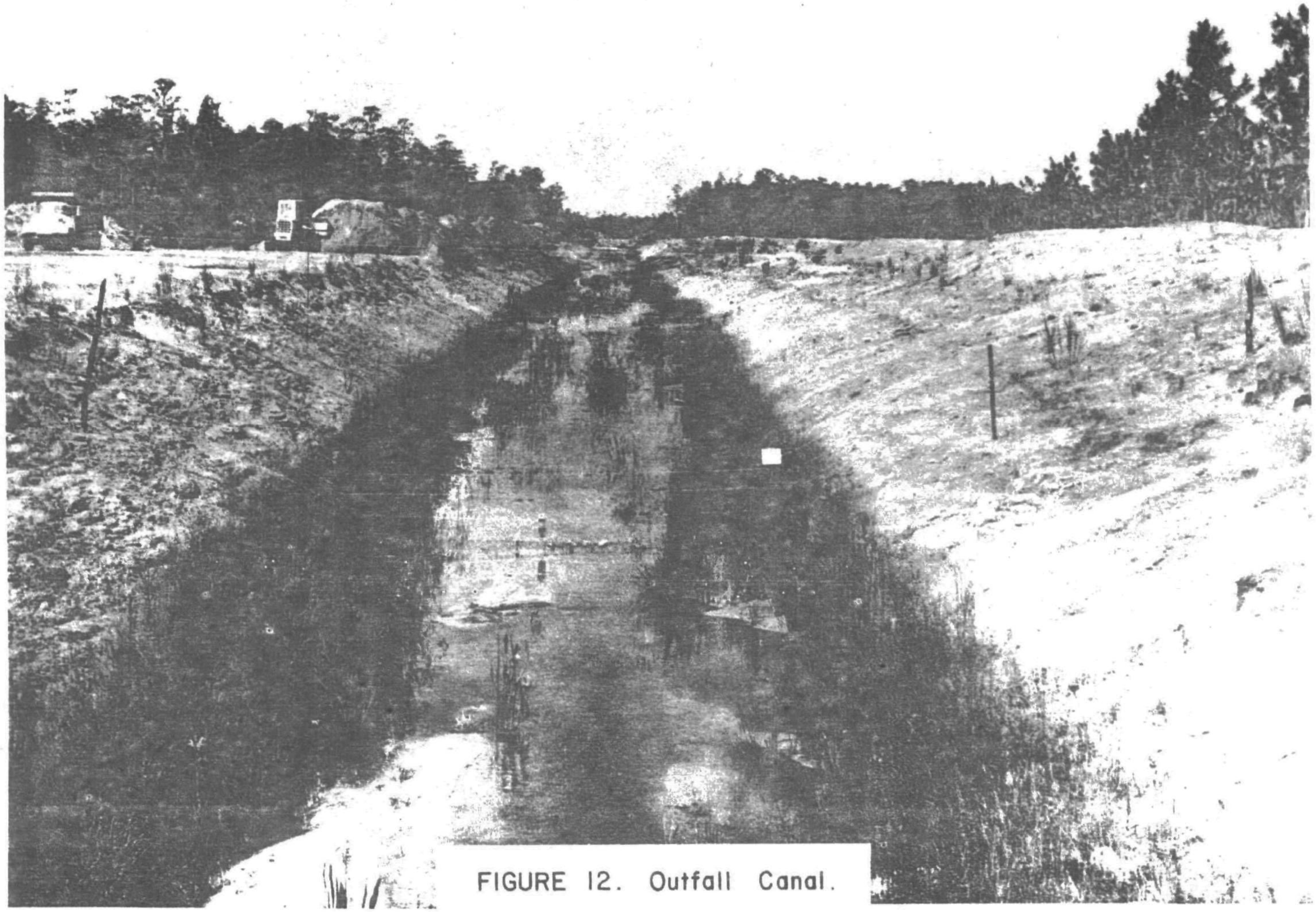

FIGURE 12. Outfall Canal.

FIGURE 13 Main Channel of the Little Econlockhatchee River.

minimum lowering of the ground water table. Accordingly, only one-half of the canal was cut initially in its entire length. Later, the canal was excavated to its full design width. To lessen turbidity, which appeared in the Little Econlockhatchee River during construction, it was necessary to partially dam the outfall canal and to pump the water to bordering fields while excavation was under way.

The landfill site has been subjected to several occurrences of high intensity rainfall following the completion of the first half of the outfall canal. During these occurrences, no flooding of the areas served by the drainage system has been observed. Neither has the depth of water in the canal been of any significance. This would indicate the canal is adequate for preventing flooding of the demonstration site.

Drainage Channels. A network of drainage channels has been established for the demonstration site (Figure 14). The network includes (1) main drainage channels designed to prevent surface waters from entering the landfill and to provide a collection system for rainfall runoff, and (2) a series of minor drainage channels to be constructed in the "demonstration cell" area as a means of permanently lowering the ground water table. Additionally, the open cells act as natural catch basins during periods of heavy prolonged rainfall. Waters so collected move laterally into the drainage channels at a very minimal rate.

The main channels are designed for a 20-foot bottom width and 2 to 1 side slopes. The average design depth is nine feet with a maximum anticipated water depth of three feet. The cell channels are spaced at intervals of 300 feet. These cell channels are designed for a 3-foot bottom width and 2 to 1 slopes. The average design depth for these cell channels is eight feet with an anticipated maximum water depth of three feet.

As previously mentioned, there have been several occurrences of intense rainfall at the project site. Aside from some cells, there has been no flooding of areas drained by the channel system during these rainfall periods. In the drained areas, the water table has been drawn down at least five feet with no detectable rise during heavy rainfall periods.

Ponds. The construction of two ponds for the collection of surface runoff and possible leachates was planned as a necessary first phase activity. Pond "A", located near the "demonstration cells" (See Figure 15), has a surface area of seven acres. The construction of this pond was expedited by excavating a perimeter channel with a dragline as a means to lowering the water table. A self-propelled, self-loading earth mover was utilized in completing the excavation. Pond "B", originally planned for the "control cell" area, was to have a surface area of four acres. Following special ground water movement studies by the retained ground water geology consultant, it was found that construction of Pond "B" could lower the ground water level in the "control cell" area and adversely affect the control conditions necessary to the Demonstration Project. Accordingly, the construction of Pond "B" was halted following the excavation of the perimeter channel.

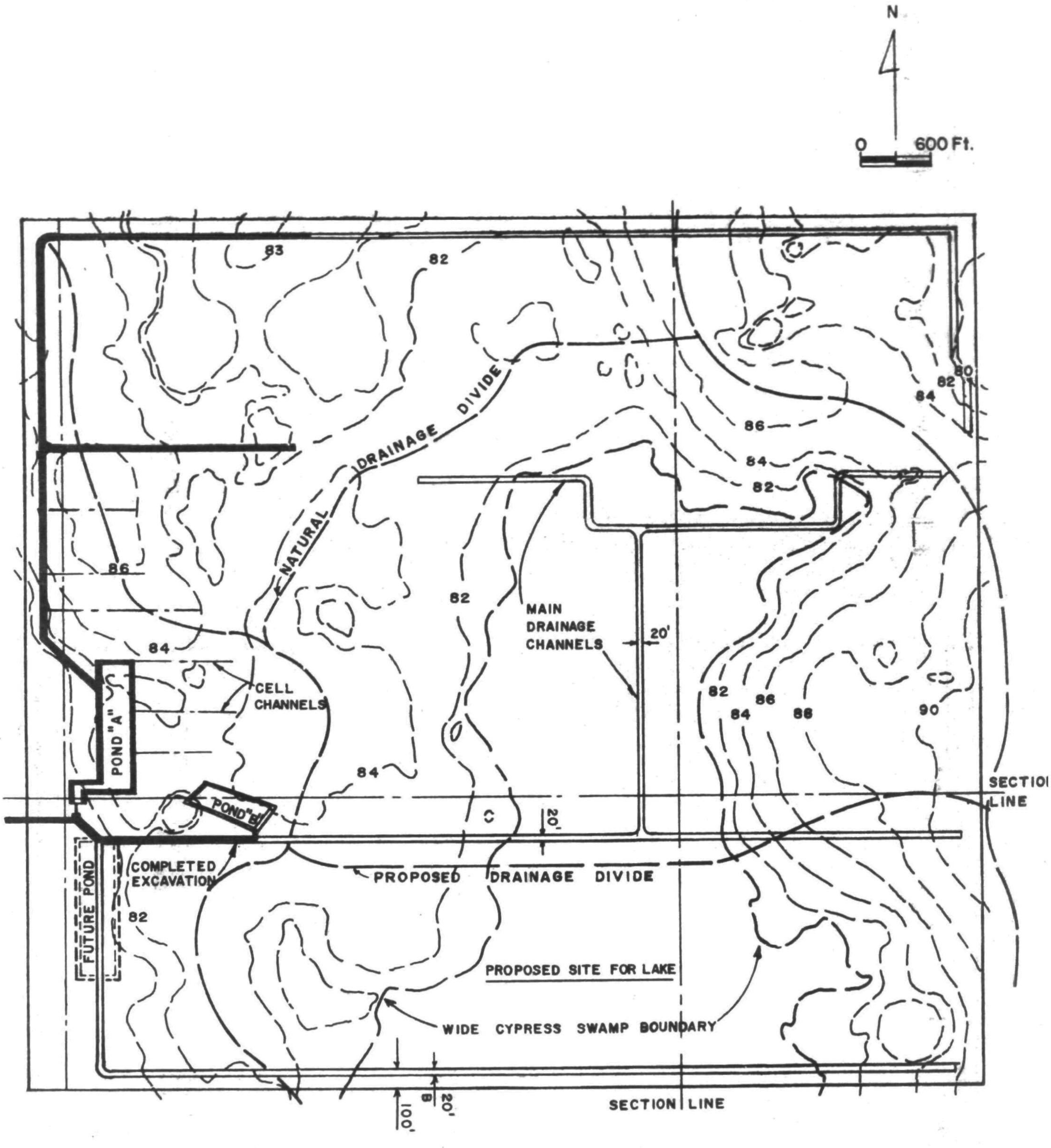

FIGURE 14. Master Drainage Plan, Orange County Landfill Site.

FIGURE 15. Drainage Pond A, Orange County Sanitary Landfill.

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Facilities. Extensive facilities have been constructed at the demonstration site (Figure 16). These provide for optimum operation and management of the project area. The completed facilities are: (1) an air-conditioned concrete-block office building including a small lounge, storage room, and complete sanitary facilities (Figure 17); (2) a concrete-floored, prefabricated metal service and maintenance building including three bays for equipment service and maintenance, and equipped with a two-post lift, an air compressor, and a 20-ton overhead bridge hoist (see also Figure 17); (3) a concrete-block scale house, housing a 50-ton capacity Fairbanks-Morse scale with an automatic printing mechanism (Figure 18); (4) a pumphouse, chlorinator, a 1,000-gallon water tank, and pump to serve a 6-inch potable water well; (5) a washrack, including a prefabricated metal storage building, equipped with a high pressure pump for trailer washing, (6) a fuel tank storage area with pump island; and, (7) septic tanks for receiving sanitary waste and for trailer washing waste.

Landfill Operations

Initially, the hours of operation for the landfill activities were 7:00 a.m. to 6:00 p.m., Monday through Friday, and 7:00 a.m. to 12:00 noon on Saturdays. The landfill is now open from 8.00 a.m. to 5:00 p.m. Monday through Sunday, for a total open period of 63 hours each week when wastes are accepted at the demonstration site. The County restricts the individual personnel work week to 40 hours; however, some equipment is on 80 hours/week operation. Various personnel shifts are needed for operation of the landfill.

When first opened, the landfill operation was accepting approximately 30 loads of refuse each day, or about 600 cubic yards. The estimated density of these loads was approximated at 500 pounds per cubic yard. Prior to March 1973, the landfill had accepted an average of 11,700 tons per month. Since that date and the coincident closing of the Porter Landfill and activation of a transfer station at that site, average monthly waste deliveries to the demonstration site have been on the average of 8,500 loads or about 17,500 tons. The total tonnage of solid waste delivered to the demonstration site during the project period was 280,047 tons.

Daily traffic volumes into the site have averaged between 250 and 275 vehicles in the following approximate proportions:

Monday through Saturday Morning	-	50% commercial, 50% private
Saturday Afternoon	-	20% commercial, 80% private
Sunday, All Day	-	2% commercial, 98% private

Of the approximate equal number of commercial and private vehicles during weekdays, tonnages delivered are approximately 95% by commercial haulers and 5% by private vehicles. Weekend deliveries by private vehicles are predominately bulky trash of low weight. There have been no consistently pronounced peak delivery days.

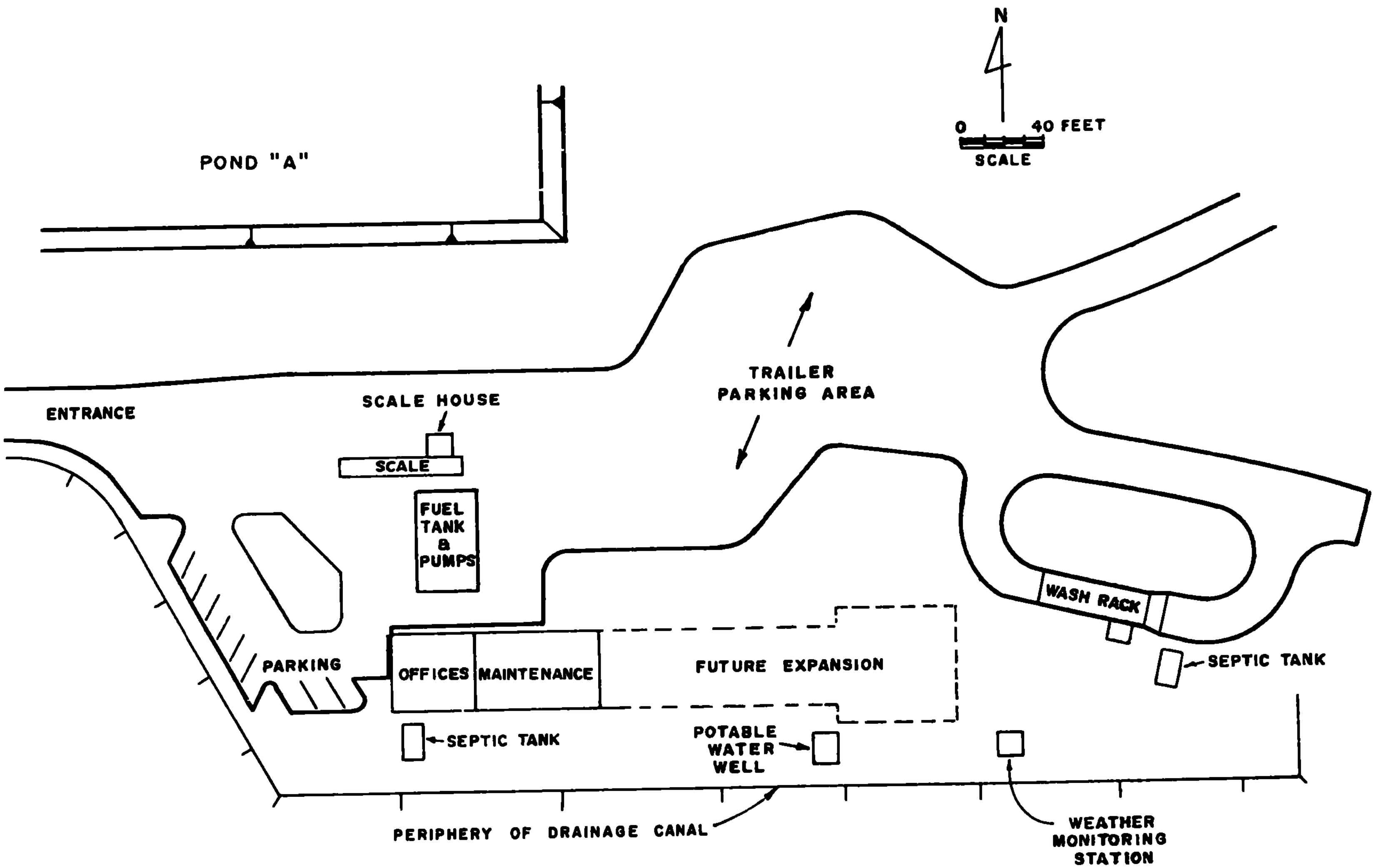

FIGURE 16. Orange County Sanitary Landfill Operation Control, Maintenance and Service Facilities.

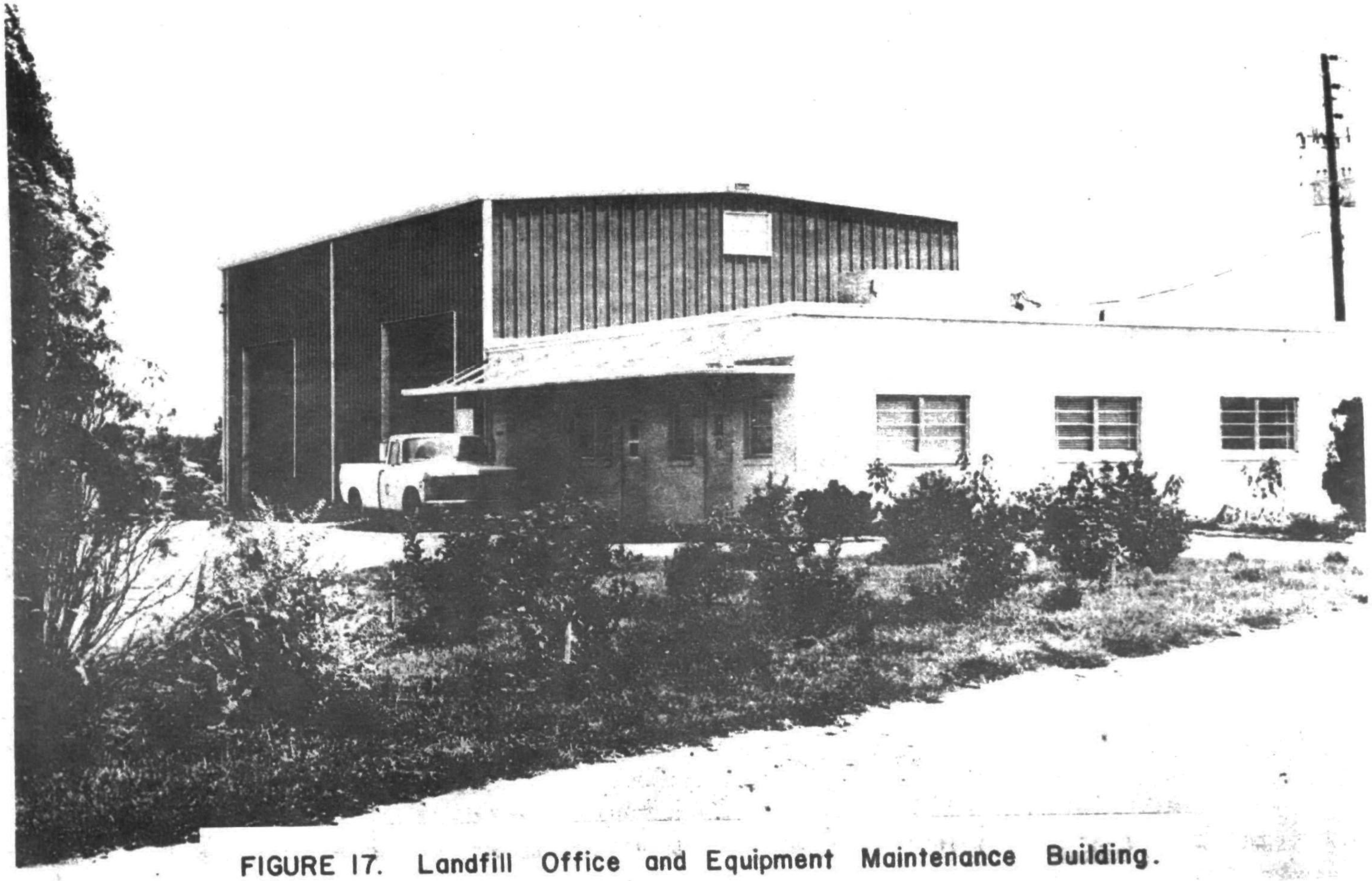

FIGURE 17. Landfill Office and Equipment Maintenance Building.

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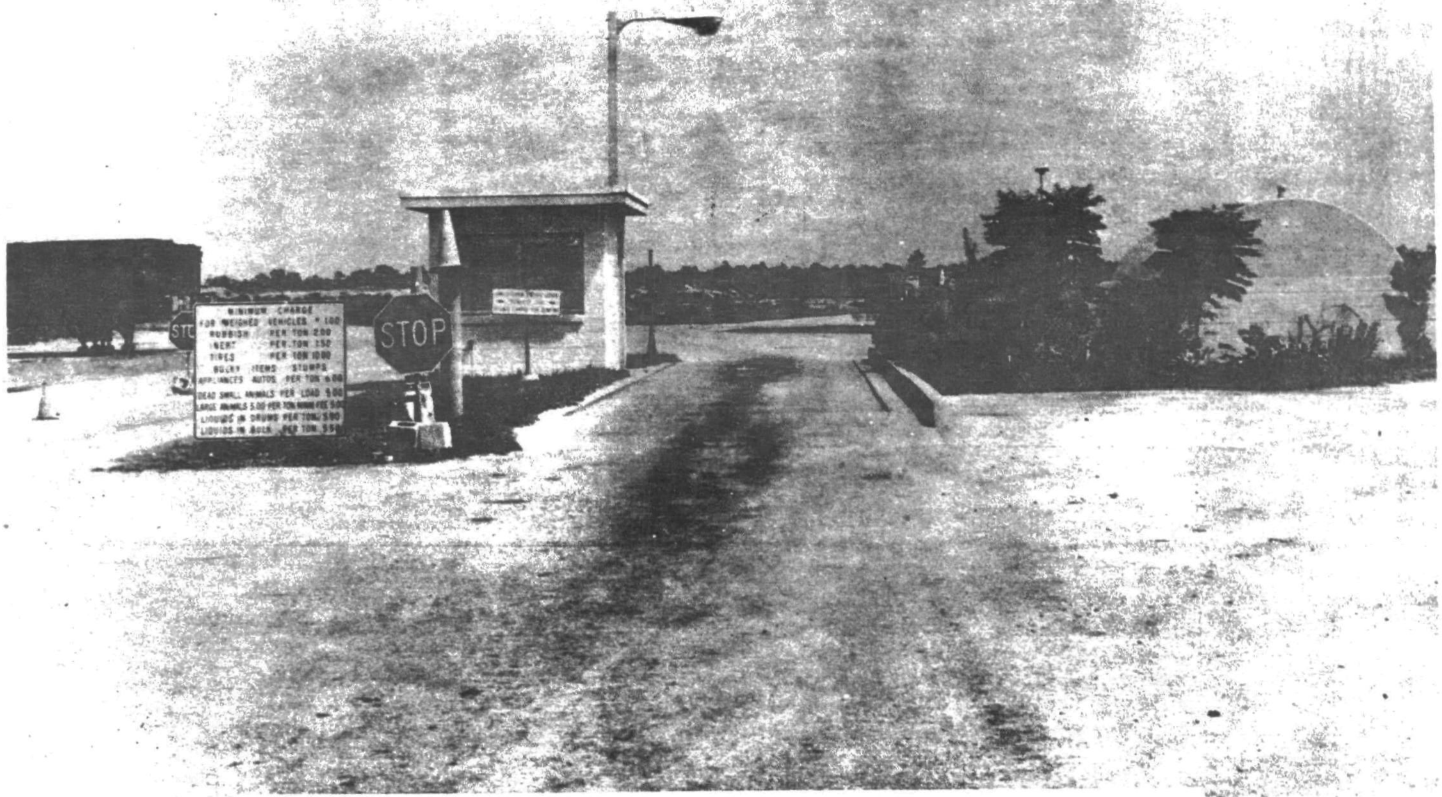


FIGURE 18. Scale House, Orange County Sanitary Landfill.

Sanitary landfill operating experience gained in the three years of operation is reflected in the generally smooth functioning of the Demonstration Project in accordance with established procedures, and reflects credit upon supervisory personnel in their ability to adapt to situations as they arise. The capability of equipment operators to assume added functions or to "fill in" for absentees has created assurance that operations can be controlled at all times.

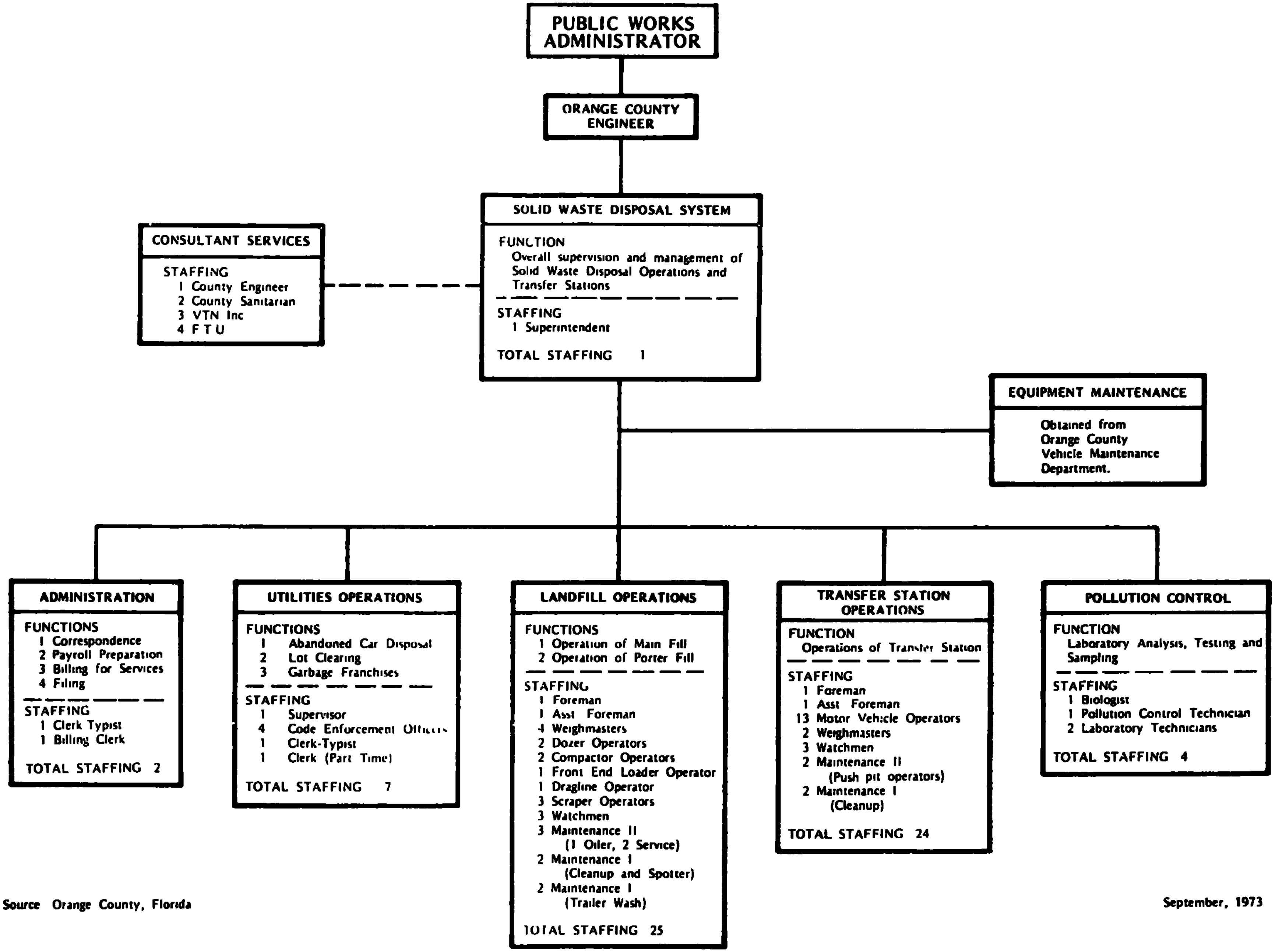
Personnel. Personnel administration has been the responsibility of the Superintendent of Orange County's Solid Waste Disposal System, with various key members and staff assigned on a limited basis to the overall administration of the Demonstration Project.

The initial operations staff included: (1) two dozer operators, responsible for all construction, compaction and daily covering; (2) one self-propelled scraper operator, assigned to cell and road construction, and to provide assistance in the daily covering operation; (3) one weighmaster; and (4) one landfill foreman assigned to the Demonstration Project on a half-time basis As indicated earlier (see Acknowledgements), personnel from the County Pollution Control Department are assigned to Orange County solid waste disposal operations.

The operations staff has been expanded to include: (1) nine heavy equipment operators; (2) four weighmasters; (3) four maintenance men; and (4) three watchmen. This staff is required to operate on a multiple-shift basis and provide backup staffing. In addition, administrative positions include: (1) the Superintendent of the Solid Waste Disposal System assigned to the Demonstration Project on a half-time basis; (2) one landfill supervisor; (3) an assistant landfill supervisor; (4) two clerks assigned on a half-time basis; and (5) four full-time and one part-time personnel assigned to the waste disposal operations but working in the County Pollution Control Department. The total number of personnel is influenced by landfill operating hours as established by the Board of County Commissioners, and by their policy of restricting the normal employee work week to 40 hours. Accordingly, the expanded manning supports operations on a necessary multi-shift basis so as to comply with the instruction of the County Commissioners.

The Orange County Solid Waste Disposal organizational chart is included as Figure 19. The manpower requirements for transfer operations are shown on the chart since these operations are an integral part of the disposal program even though they operate separately from the landfill activities. Most of the position titles are self-explanatory; however, the dragline operator has additional responsibilities covering drainage improvement construction. The self-propelled scraper operators are also responsible for road construction.

Equipment. The equipment initially used in this landfill operation was equipment either obtained for the Demonstration Project or transferred from the old landfill and dump operations. The equipment now in use includes: (1) one recently overhauled International Harvester TD-20 dozer (14 years old) with blade used for compaction, cell construction and cover; (2) one new International Harvester EC-270 (21-cubic yard, self-propelled scraper pan), approximately 3 years old, used for cell construction, clearing, road building and cover hauling; (3) one International Harvester TD-15 dozer (approximately 14 years old) with 4 in 1 bucket; (4) one Rex-Trashmaster



Source Orange County, Florida

September, 1973

FIGURE 19 Organization Chart for Solid Waste Disposal System – Orange County, Florida

Compactor Model 3-50 (approximately 6 years old); (5) one Northwest 95, 3-cubic yard dragline; (6) two International Harvester TD-25C dozers with blade; and (7) the required service trucks.

Design and Construction Procedure. The primary purpose of this Demonstration Project is to develop proper landfill design and operating techniques for areas affected by high water table conditions. Accordingly, two basic approaches to landfilling were formulated. These approaches involved (1) landfilling in non-dewatered trenches, called "control cells", and (2) landfilling in "demonstration cells", or trenches having dry bottoms due to the lowering of the water table. The two types of cells are illustrated in Figure 20.

The Control Cell. The basic design of a "control cell" is shown in Figures 21 and 22 Development of a cell required excavation of a trench to a depth of eight feet. Excavation to the water table was made with a self-loading scraper, with final excavation to the cell bottom below the water table being made by the dragline. Due to potential problems with floating materials within trenches, sections of the cells are separated by earthen dikes. Cells numbered 1 through 7 are dimensioned as 100 feet wide and 500 feet long. Cells 8 through 14 were to be constructed immediately to the east; however, at the request of the Environmental Protection Agency, only Cells 8 and 10 were actually excavated. The dimensions are 120 feet wide and 600 feet long for Cell 8, and 100 feet by 600 feet for Cell 10.

Since solid waste was deposited at times below the water surface, control cell filling and compaction was undertaken to the extent possible, to include a six-inch daily cover and a final two-foot earth cover as part of the design. Initial plans called for filling to within two feet of the ground surface in a single lift with a final two feet of cover. Experience with the first cell, however, showed large quantities of excavated material unused, and a decision was made to fill in two six-foot lifts. The first lift proceeded from west to east, applying daily cover as was practical in the relatively damp conditions. The second lift then proceeded from east to west, being finally covered with two feet of earth. Thus each cell consists of approximately 12 feet of solid waste fill, including daily covers, and two feet of final cover.

The Demonstration Cell. The "demonstration cells" were of two basic designs initially, depending on anticipated use. These were (1) cells for disposal of small amounts of wastes as a convenience to the public and (2) cells for use of county trailers and commercial franchised haulers. Expediency in providing disposal space to mechanically unloaded vehicles in addition to traffic safety considerations were the primary reasons for separating the professional drivers from the individual homeowners and smaller haulers. Both types were built in areas permanently dewatered to a depth of at least five feet by the construction of drainage channels. The initial basic design for the public cells (designated CP) is shown in Figures 23, 24 and 25. This design was found inadequate due to the large quantities of waste handled and the design was subsequently changed to the progressive trench type, in which daily cover excavation provides the trench space required for the next day's wastes. The overall depth of the fill is eight feet with final covering of at least two feet. "Transfer trailer" cells (Figure 26) are built in one eight-foot lift with a minimum of two feet of final cover. These two types of "demonstration cells" were operated

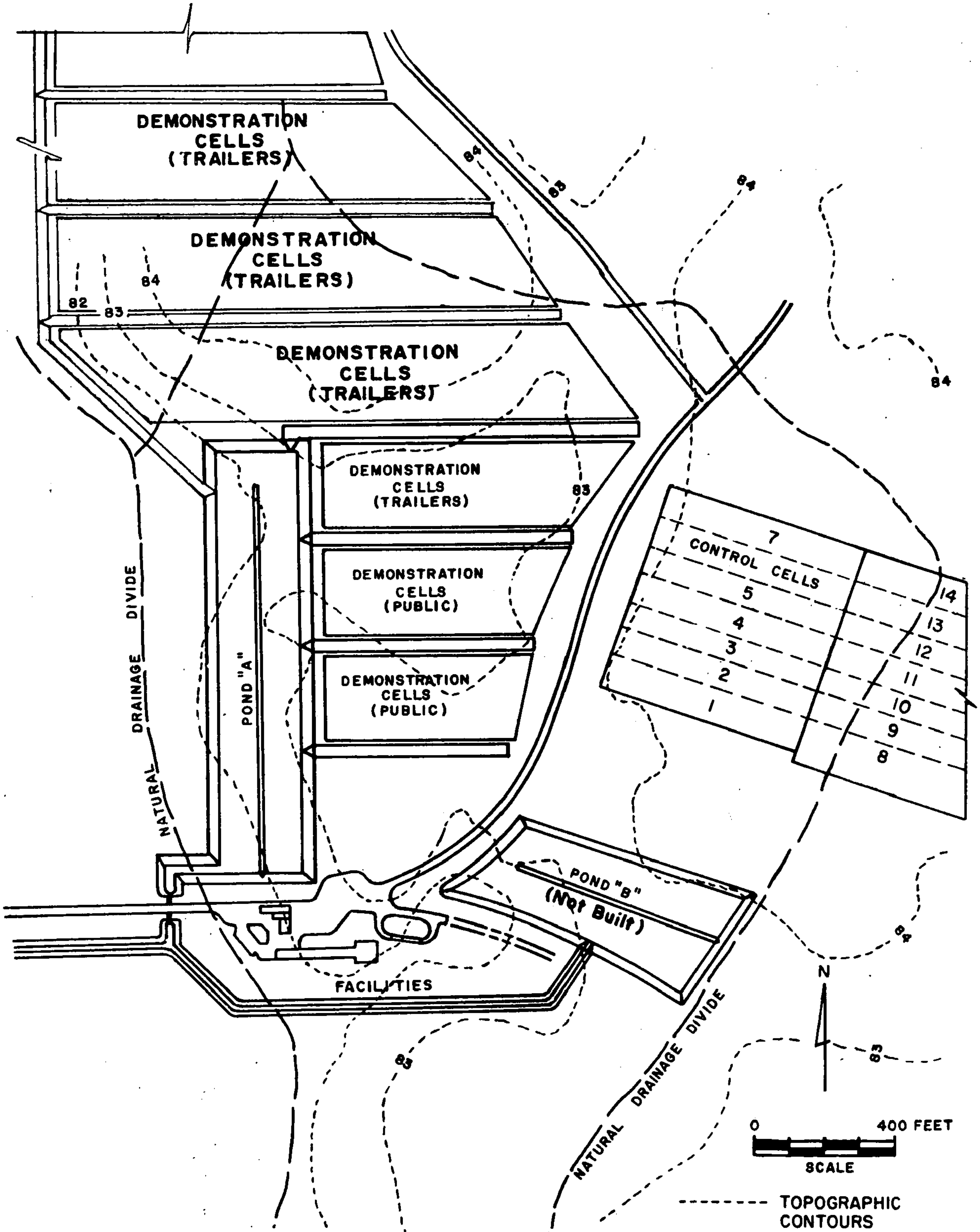


FIGURE 20 Landfill Site Operations Plan through June 30, 1973, Orange County Sanitary Landfill.

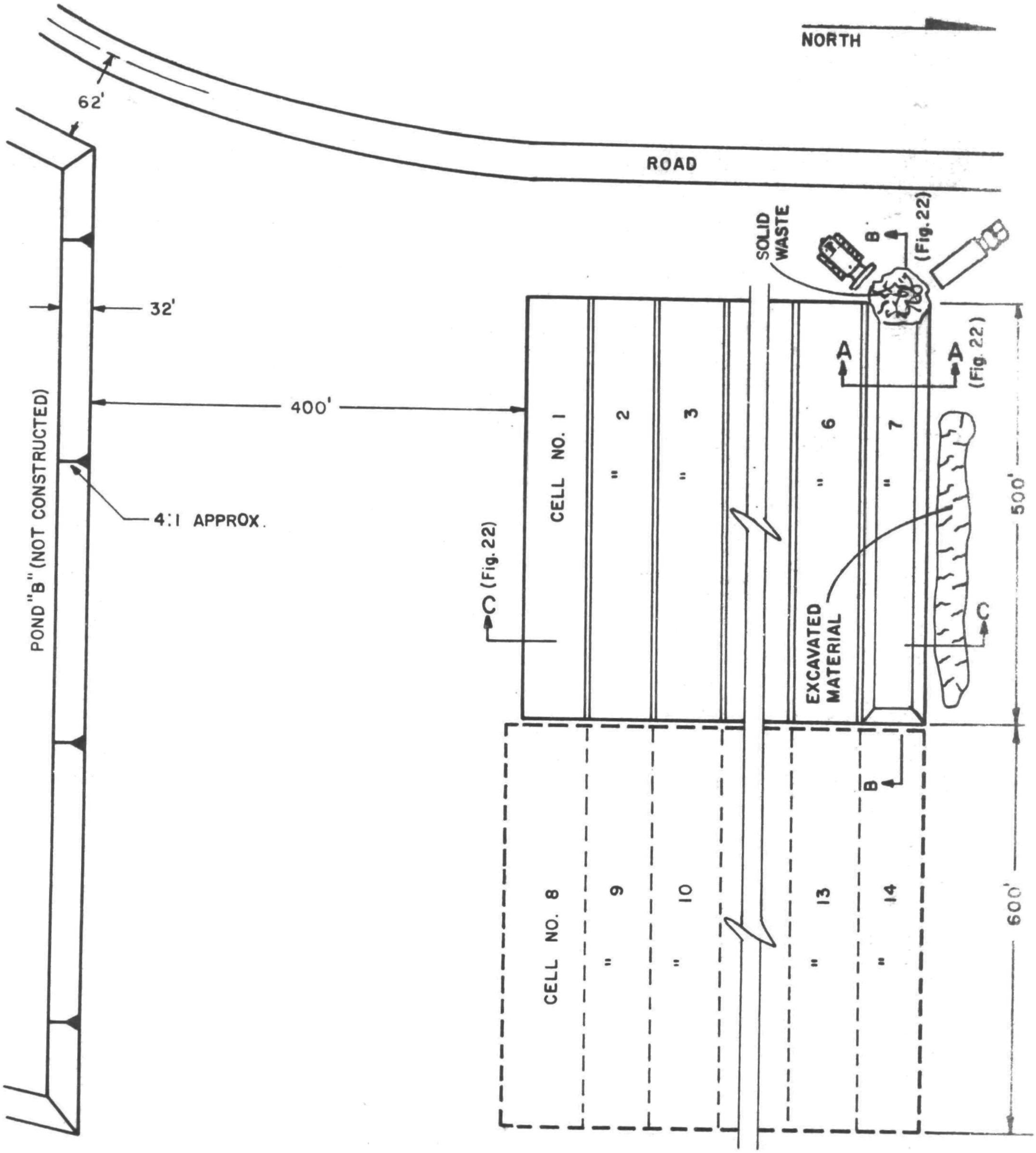


FIGURE 21 Plan View of Control Cells

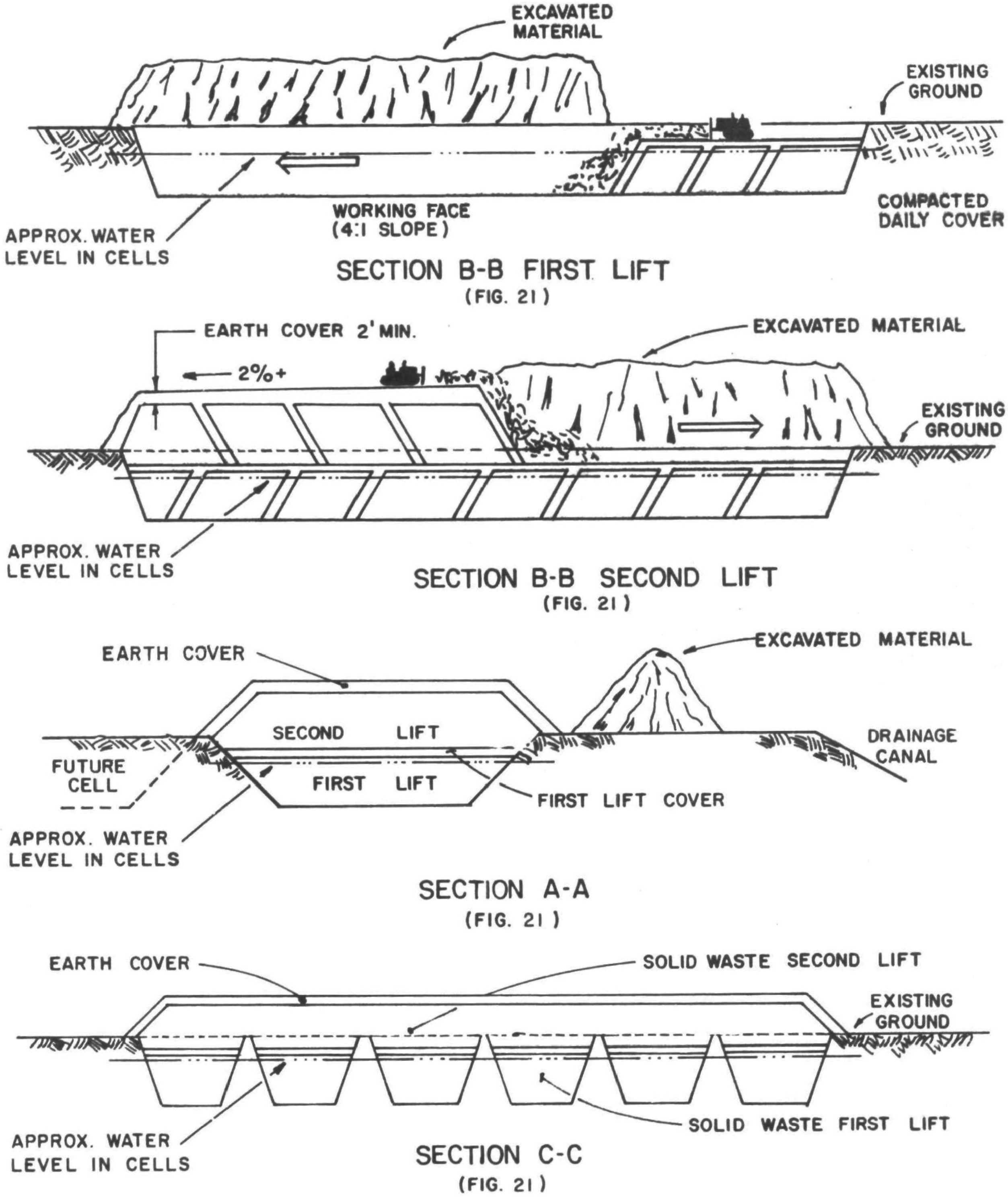


FIGURE 22 Construction Sequence and Cross Sections of Control Cells

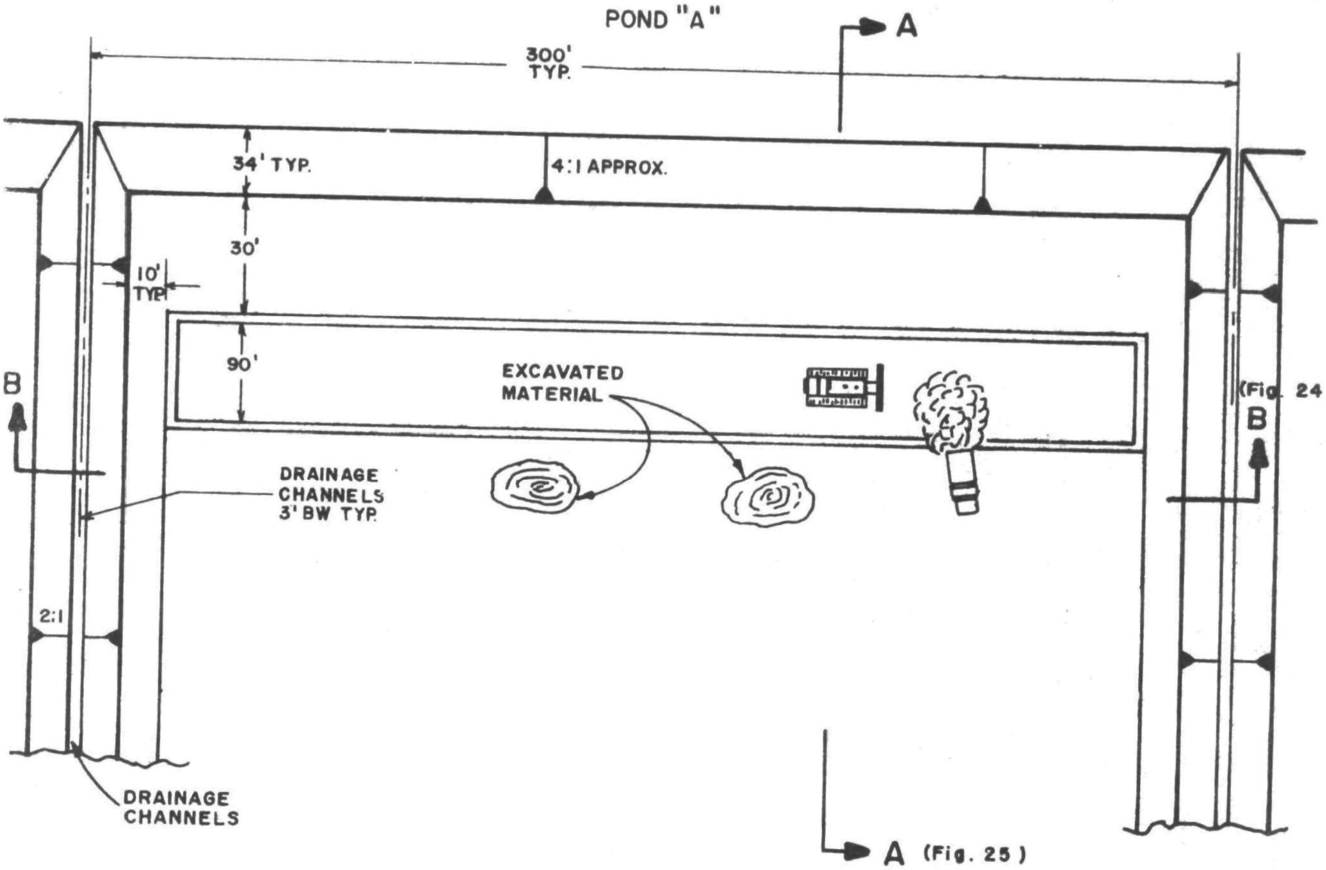
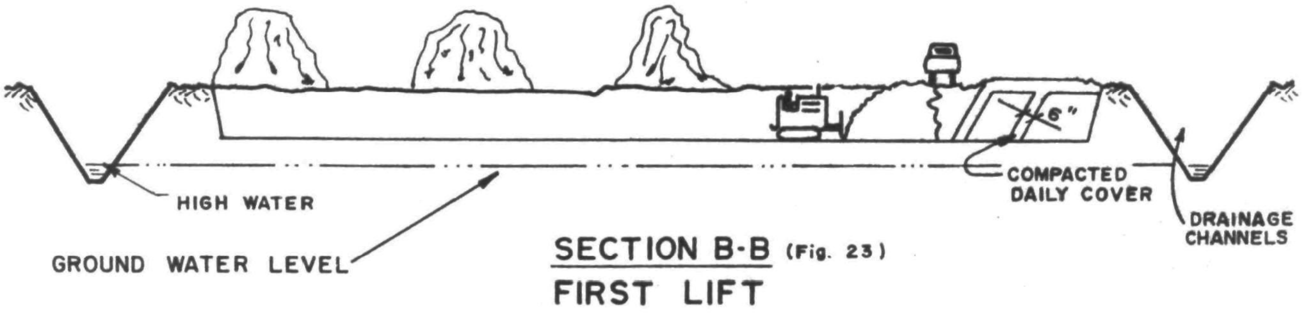


FIGURE 23 Plan View of Original Public Access Demonstration Cells



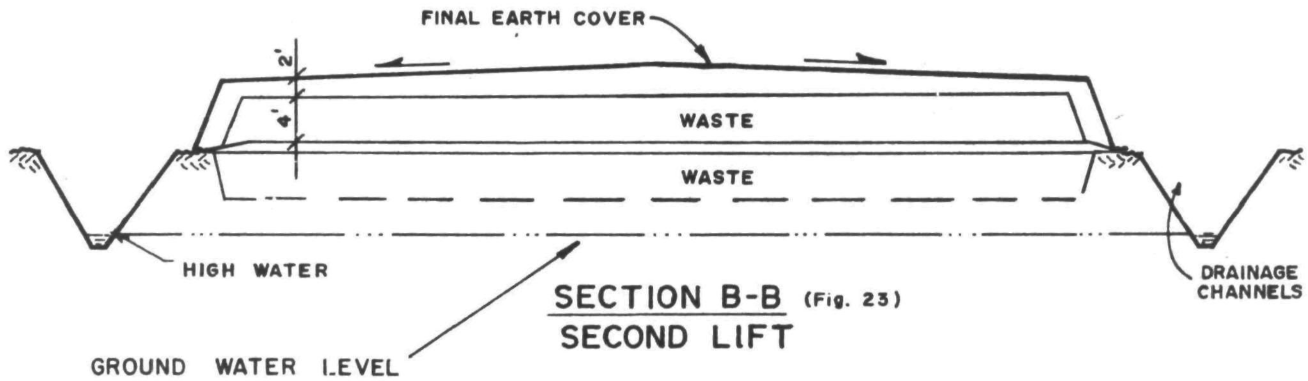


FIGURE 24 Construction Sequence and Cross Sections of Original Public Access Demonstration Cells

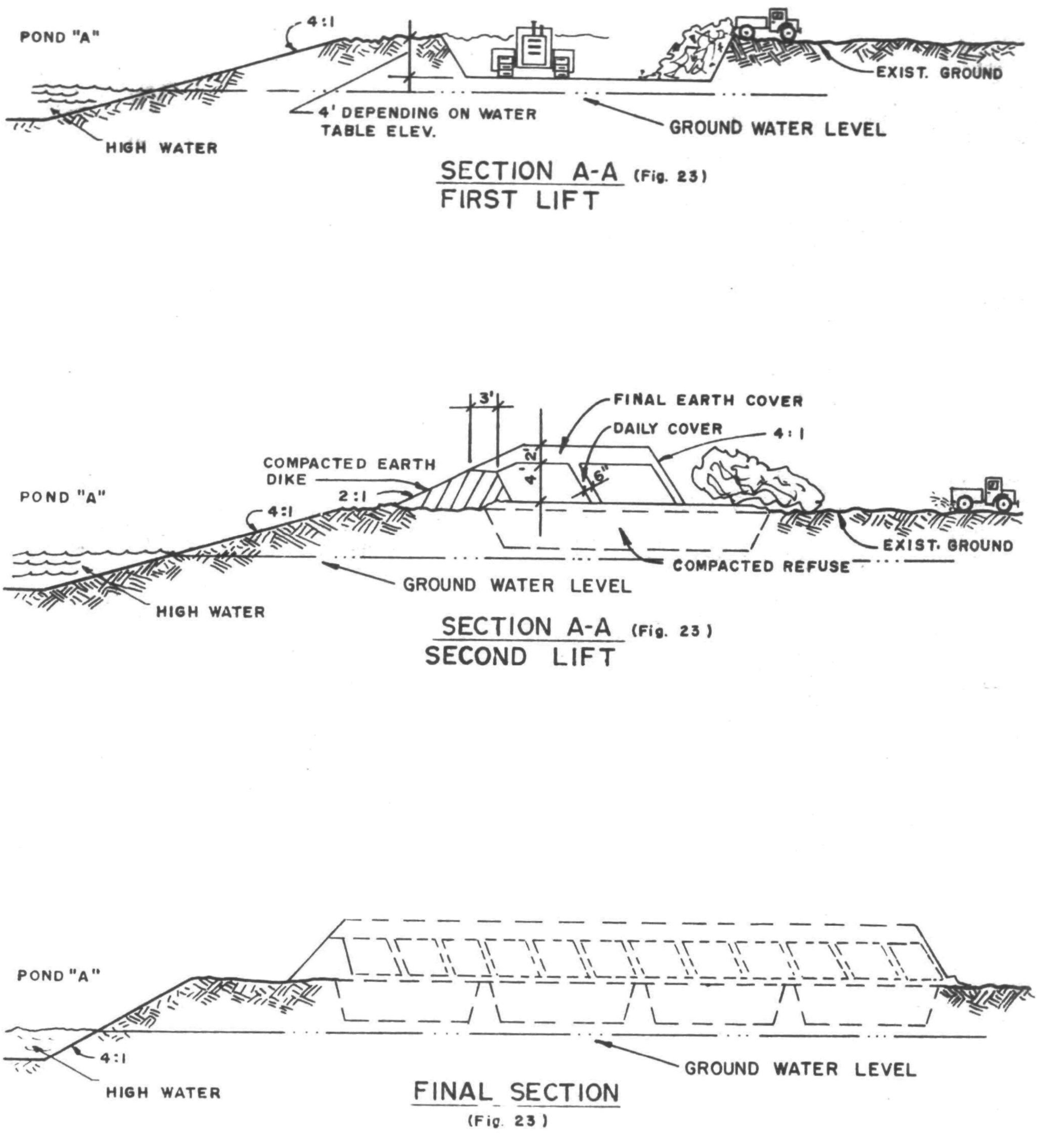


FIGURE 25 Construction Sequence and Cross Sections of Original Public Access Demonstration Cells

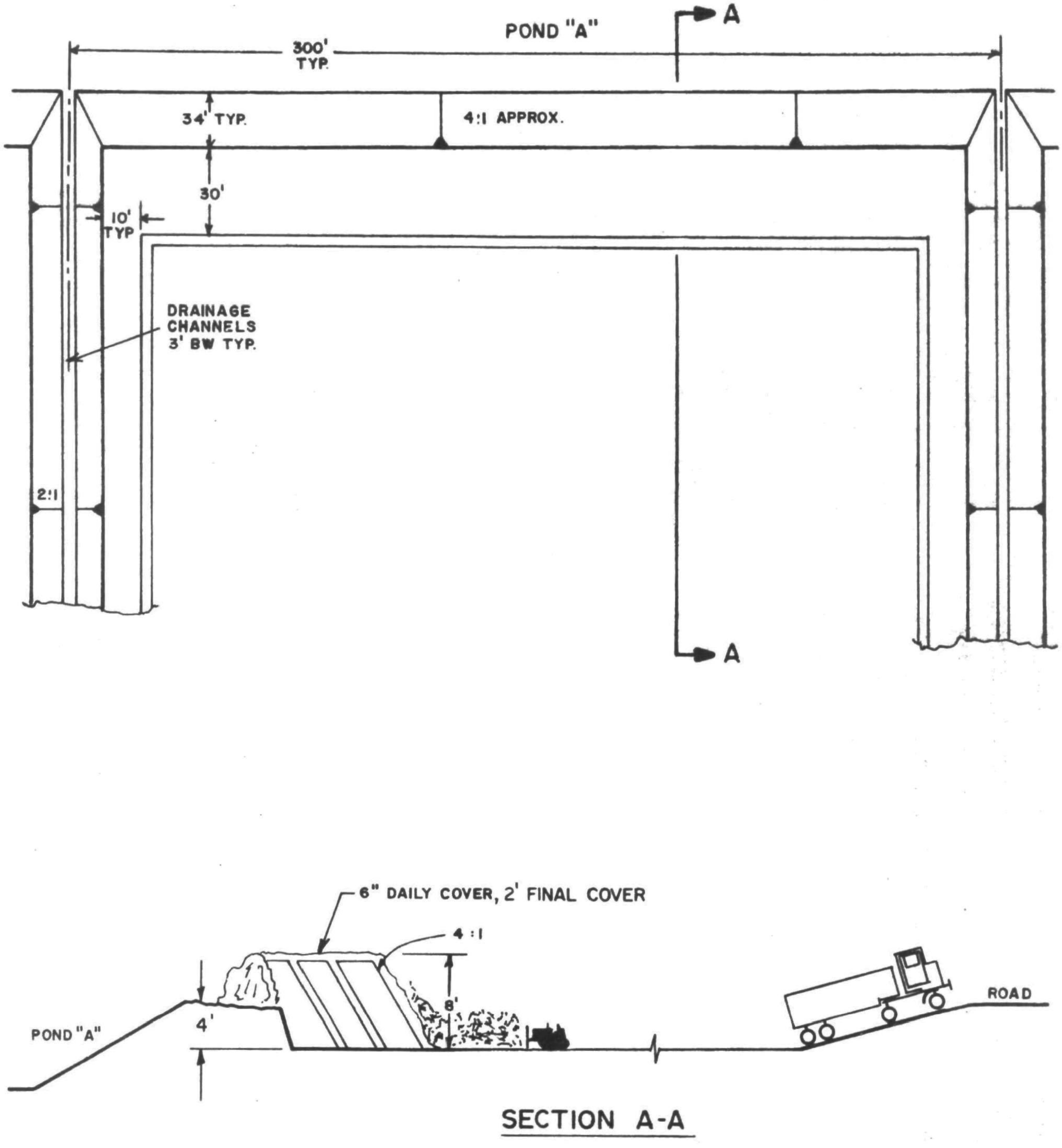


FIGURE 26 Plan View and Cross Sections of Transfer Trailer Demonstration Cells.

separately in order to maintain a safe and orderly traffic flow and to expedite waste handling operations for trailer and commercial accounts. Since February 1973, however, the distinction between public and trailer cell operations was discontinued for economic and efficiency considerations since added equipment and personnel were required to support the separate operations. There were no problems encountered after discontinuing use of the public cell.

Public use cells, designated as CP1 and CP2, were each 260 feet wide and 600 and 700 feet long, respectively. Transfer trailer cells, designated presently as CTO, CT1, CT2, CT3 and CT4, are each 260 feet wide and 800, 1400, 1300, 1000 and 800 feet long, respectively.

The surface slopes for all demonstration cells are at a grade of at least two percent to the nearest drainage channel, with the slopes being periodically regraded as required to compensate for cell consolidation and settlement. Figure 27 shows a typical load of refuse being unloaded at the bottom of the working face of a demonstration cell.

Operational Experiences. Since June 7, 1971, solid waste disposal has been in both "demonstration" and "control" cells, generally on an alternating schedule to permit even distribution and facilitate more precise costing analyses as required by the project grant. Public use disposal was initially confined to cells CP1 and CP2 so as to alleviate congestion, promote orderly and rapid traffic flow, and to avoid including unweighed refuse quantities in the economic analyses of the project. These cells have been able to accommodate, on the average, up to 36 vehicles per hour; however, some vehicles take as long as 90 minutes to unload. Positioning of a full-time spotter and traffic director at the unloading face reduced such excess vehicle positioning time at the cell edge.

The first "demonstration trailer" cell (CTO) was excavated to a three-foot depth, with the remaining one foot of excavation to be available for daily and final cover. However, difficulty was experienced in attempting to run the loaded scraper up the open face of the cell. Scraper routing was subsequently redirected to the top of the cell for more satisfactory operation. Daily and final top soil cover for trailer cells currently in use is now obtained from excavations of the adjoining cell, that is the next cell to be used for refuse disposal. Thus cover material is readily available and need be transported a minimum distance. Trailer cells are designed to accommodate eight feet of refuse in single lifts, and will receive a two-foot top earth cover. The depth of the trench varies depending on the elevation of ground water. A two-foot minimum separation between the ground water and the bottom of the cell was maintained to provide for some treatment of the leachate and to maintain a dry cell bottom condition essential for equipment movement.

A series of "control" cells, designated CC1 through CC7, were initially excavated into the water table to a cell depth of eight feet. Refuse filling began at the cell point nearest the on-site roadway and progressed eastward in a six-foot lift to the cell end. The solid waste was compacted. Daily covering was applied whenever the solid waste was exposed above the water level. Upon reversing fill direction back toward the road, an additional six-foot lift was added,

FIGURE 27 View of Typical Refuse Being Accepted at the Orange County Sanitary Landfill.

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similarly compacted and finally covered with a two-foot earth cover to complete the cell. Cell CC1 was originally designed to be filled only to the ground level, but to continue this type of operation in all cells would have resulted in the creation of excessive soil stockpiling. The decision to increase all control cell refuse depths to 12 feet, in addition to utilizing some stockpiled soil materials for road construction, served to more adequately utilize excess excavated soils on the site. Although Cells CC8 and CC10 were excavated, refuse disposal therein has not been effected at the suggestion of the Environmental Protection Agency. Since January, 1973, filling of "control" cells has not taken place because it was felt sufficient experience and data were then available with which to assess excavation and filling operations under wet conditions.

A summary of demonstration project cell construction through June 30, 1973 is presented in Table 1.

During the project time, rain waters accumulated once at the working face during an abnormally heavy and prolonged precipitation period. This condition interfered with both access to the face by vehicles and with equipment operations. Experimentation with pumping provided the relief necessary to maintain the required dewatered proper conditions within the cells. Lateral movement of excess waters through the cell walls as well as percolation through the cell floors has been minimal. To speed this water removal, the pumping procedure will remain in effect for future operations as weather conditions dictate.

Starting March 1972, the Superintendent of Solid Waste Disposal System, acting under the authority set forth in the Code of Orange County: 15-11, gave notice that such industrial wastes as acids, alkalies, fungicides, pesticides and petroleum products would be accepted in limited quantities and under controlled conditions. For disposing of these wastes, the following procedure is adhered to for personnel safety and pollution prevention.

(1) Acids and Alkalies - Arrangements are made in advance either by letter or telephone, giving time and date of arrival of these wastes. Waste must be neutralized. A certificate must accompany shipment, giving name of original material, date and manner it was neutralized, also type and number of containers. The certificate must be signed by the producer of the waste or an authorized agent. Empty containers must be rinsed by the customers before bringing them to the landfill for disposal.

(2) Oils and Naphthas - These wastes are accepted in limited quantities, with prior approval of the Orange County Landfill Supervisor or authorized agent. The landfill will accept not more than two (2) fifty-five (55) gallon drums on any one load. Approval may be obtained by a telephone call to the Landfill, furnishing time and date of desired delivery of these materials. If the materials cannot be accepted at that time, the Landfill Supervisor or his agent will give an alternate time and date.

(3) Pesticides and Fungicides - These will be accepted only if permanently sealed in concrete. Empty containers must be rinsed out by customers before bringing to landfill for disposal.

TABLE 1

CELL CONSTRUCTION SCHEDULE
June 7, 1971 through June 30, 1973

Cell Designation	Start Refuse Fill	Complete Fill and Cover	Tons Refuse Deposited
CP1	2-14-72	10-16-72	23,229
CP2	10-4-71	2-19-73	23,677
CT0	6-7-71	10-11-71	21,995
CT1	3-20-72	8-20-72	43,013
CT2	2-19-73	6-19-73	68,686
CT3	6-20-73	In Progress	6,798
CC1	10-12-71	1-25-73	14,510
CC2	2-5-72	9-15-72	11,017
CC3	10-12-71	2-4-72	13,278
CC4	3-10-72	10-17-72	13,853
CC5	12-1-72	1-25-73	11,298
CC6	12-12-71	3-20-72	15,826
CC7	10-16-72	1-18-72	12,720
CC8	3-4-73	---	147

When deposited, these wastes are done so as to be dispersed within the cell to the maximum extent practicable and are deposited only under conditions of controlled supervision. The cooperation of industrial elements in this regard has been excellent.

Users Comments. Comments solicited from franchised haulers suggest that their preference in landfill operation favors the demonstration cell method since their vehicles need not pass over uncovered waste in the unloading operation, thus saving wear and tear on tires and possible vehicle damages. Likewise, the possibility of vehicles becoming mired is minimized. In the "control cell" unloading was accomplished from the refuse lift itself. Unfavorable reaction regarding access to "control cells" during rainy periods resulted when vehicles became immobilized in the approaches to the cells. In addition to hauler inconvenience, the slowdown in unloadings became evident in the "backed-up" traffic waiting space to unload, primarily because of the narrow cell face.

Some user complaints were registered pertaining to the mixing of tree stumps in "control cells" along with routine refuse because of the likelihood of vehicle damage. This problem was overcome by depositing such stumps in the cell bottoms only.

With minor exceptions, users have been most cooperative and are apparently satisfied with the manner of operations and business-like approach assumed by the County. In like fashion, landfill supervisory and operating personnel make every effort to extend courtesies and assistance to avoid possible customer dissatisfaction.

Operator Comments. It was considered appropriate to obtain comments from equipment operators and other landfill employees as to problems encountered during the grant period and suggestions for improvement in operating techniques. Insofar as cell work is concerned, preference was extended to operating in the "control cells" for the reason of dust control, whereas "demonstration cell" work was preferred as a better overall operating method. Working from the top of cells was initially preferred because of the greater ease of maintaining levels for both the refuse and the cover, as opposed to working the cell face from bottom to top. Experience gained in the latter type operation has since acquainted operators with both methods and there is no longer a particular preference for either method.

Dozers in the range of 50-55,000 pounds gross weight equipped with large blades are considered necessary to handle the waste volumes and the bulky refuse materials received at the site. Smaller equipment would be inadequate and inefficient. Similarly, a dozer with a bull-clam bucket was not desirable for this size and type of operation, due to the small volume of solid waste or earth that can be moved by this piece of equipment.

The effects of extended downtime for equipment maintenance generally results in accelerated efforts and possibly overtime hours to catch up. It was felt that expedited maintenance should be stressed to eliminate this problem.

Increasing magnitude of operation requires increasing administrative functions which are generally initially objected to by staff. Such objections were usually overcome with time and are now infrequent and individual in nature.

Equipment Evaluation. While most heavy equipment is designed for rugged operations and may function extremely well under varied conditions, their use under conditions peculiar to sanitary landfilling presents problems, or requires restrictions to operation which may somewhat limit their capabilities. In a wet cell operation, as in the "control cell", the ability to fully compact at least the first refuse lift is diminished for fear of the equipment becoming hopelessly mired in the very wet underfooting. Thus caution had to be exercised in the placement and cover of the first lift of this type cell. However, refuse densities in these cells were generally higher than those experienced in the dewatered cells, indicating that the wet conditions were promoting the filling of normally void spaces in the fill. The weight of standing water in the cells was not included in density calculations. Evaluation of the four major types of equipment used follows:

... Dragline. A dragline was necessary for excavating into the ground water, and it is especially needed for drainage and ditch construction and periodic ditch maintenance. The three cubic yard capacity bucket appeared to be quite practical for the magnitude of the operations.

... Dozers. Dozers should not be less than 50,000 pounds gross weight to effectively spread the quantity and type of waste handled at the landfill. Dozers were also used on the compaction operation when the compactor was inoperative. Radiator grille and undercarriage protection, as well as engine side covers, are necessary to avoid damages caused by solid materials commonly found in the fill.

... Compactor. The compactor was effective in providing excellent compaction on the slope face with an average of two passes. Excessive maintenance downtime of the present machine, due to age, prevented really efficient use. When operational, it provided effective service in both the "demonstration" and "control" cells.

... Self-Loading, Self-Propelled Scraper. This is an ideal equipment item for the excavation of large cells and for the hauling of cover materials when considering the cell widths, as opposed to the capability of a front-end loader which would require more trips per volume carried. To enhance machine longevity and to minimize maintenance, the scraper should not travel directly over uncovered refuse, but should deposit cover material in close proximity to the refuse for final placement by the dozers. The 21 cubic yard capacity unit appeared to be optimal for this operation. This machine was also used effectively in road constructions and earth stockpile operations.

Experience has shown that equipment downtime for maintenance and repairs is a problem that remains to be overcome. Machine age has been a definite factor, but the problem has been partially alleviated through the centralization of in-shop maintenance obtained from the Orange County Vehicle Maintenance Department. The retention of qualified personnel and the adoption of an effective preventive maintenance program have gone far toward reducing equipment downtime for other than servicing needs. Pride in workmanship is an existing characteristic among employees of the solid waste disposal system.

ENVIRONMENTAL ASSESSMENT

This section responds to one of the established project objectives: to investigate the physical, chemical and bacteriological characteristics of the surface waters within the project site, the drainage receiving waters, and the ground waters underlying the site. More importantly, the activities undertaken to meet this objective provide valuable baseline data for the continued conduct of the Demonstration Project. The assessment activities and pertinent findings are herein documented.

Literature Review

The literature search was a continuing part of the Demonstration Project. The search helped to shape the work on water quality analysis and added to the engineering and planning activities.

The Orange County Demonstration Project involves a sanitary landfill in a high water table area. Hence, two areas of concern would be important to a literature review, i.e., those dealing with sanitary landfills generally and those concerned with the effects of contaminants in water. Since a landfill operation consists of buried materials, obvious effects would occur first in ground waters, then pass to surface waters through the sides of drainage channels. Physical, chemical, and biological effects on waters were of prime interest; however, additional review of engineering and operational features of sanitary landfills was needed.

The literature search was approached from two directions. The first activity concentrated on accumulating bibliographies, reports, papers, presentations, books, and booklets on solid wastes and their ultimate disposal. The second was to search discipline literature, such as that existing for sanitary engineering, biochemistry, and microbiology. In this fashion, it was possible to accumulate literature and literature sources offering broad coverage of the subject and to provide a wide range of reference material. Useful references were numerous; however, much of the information found was of a general nature and did not always fit the Orange County situation. That which did fit is categorized in the following paragraphs.

Environmental Effects of Landfill. Many references, dating back as much as 40 years, (of which only a select few will be noted) refer to refuse degradation in a landfill operation and the resulting effects upon water quality.[3,4,5,6,7] The rapidity of this degradation is directly dependent on the amount of water in the buried refuse. Refuse has a capacity for absorbing water; therefore, until it becomes saturated, no water drains away as leachate. Reportedly, from 1.5 to 3 inches of water per foot of depth of refuse in the landfill operation is required for this degree of saturation.[6,7,8] For an eight foot fill, this amounts to an estimated one to two feet of rain water passing through the soil to the refuse. Considering the moisture lost through average evapotranspiration, the total rainfall required to allow for one foot of percolating water would be about 40 inches, or something less than an average year at the Orange County project site. Cover was sand and sand mixtures with little vegetative cover initially. Accordingly, it was logical to assume high infiltration through the cover in the early stage of the project and low evapotranspiration; therefore, a rapid attainment of field capacity was expected. Leachate could be expected within the first few months under conditions of high percolation. This saturation with rapid leachate movement was not experienced, a condition which will be discussed later.

As indicated by some experiences, one of the earliest contamination indicators is the occurrence of inorganic ions--particularly chlorides--in ground water.[9,10,11] Hardness, alkalinity, and total solids all show marked changes.[12,13,14] Thus, inorganic loadings become very great in the leachate. These are subject to dilution in movement away from the fill; hence, downstream effects depend on the climate and hydrology of the surrounding area. As the compacted refuse decomposes, complex organic products also will appear. These are best displayed in the high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values noted in the references. In addition to dilution, downstream effects will depend on the precipitation and ion exchange capabilities of the percolating soils and the microbial action as the material passes through subsurface strata to surface water. Both inorganic and organic material will appear downstream with concentration depending on the rapidity of movement, degree of attenuation, and the dilution occurring.

The soil through which ground water percolates to reach the drainage system may alter the microbial population by acting as a filter.[6,15] Additionally, the organic and inorganic food supplies in leachate, as well as such things as pH, may change microbial populations downstream in ground and surface water. The microbiology associated with landfills has been studied to some extent.[16,17] Both anaerobic and aerobic bacteria were found along with formation of organic acids. Coliforms and fecal streptococci were isolated. Evidence indicated bacteria in refuse belong to only a few genera. Cook, et.al.,[17] reported most bacteria as aerobic, mesophilic forms. Fungi also were reported along with algae growths in seepage. Movement and survival of organisms in soils and surface waters have also been the subject of investigation.[18,19,20,21,22,23] In porous soils movement can occur, with the extent dependent on the nature of the material. Fine grained sand appears to be the best condition for removal of microbial forms. This type sand exists at the Orange County site. Survival in ponds can occur with rates of dieoff varying, but reported to be in the order of days to two weeks. The oxidation pond at the demonstration site is protective in this respect.

A summary of leachate results by Steiner, et.al.,[24] as just one of many references, shows concentrations of both chlorides and sodium ions reaching several thousand milligrams per liter. Metals dissolved under acid conditions created by carbon dioxide and/or hydrogen sulfide along with sulfate, phosphate, or more reduced ions may increase to hundreds of milligrams per liter. Hardness will rise and total solids may range to 50,000 milligrams per liter The latter will include very high COD and BOD values and will imply some treatment prior to discharge may be needed if leachate is to be controlled. References consulted generally expressed organic contamination as COD or BOD. Other than reports on some work on nitrogen content, no detailed information was found on extensive studies which have been made concerning compounds present in leachates Similarly, little data appeared on the microbial effects downstream from landfill operations. Quantitative estimates do exist on inorganic yield or leachate per unit of fill.[5,6,7,12]

Because of these environmental effects, treatment of leachate was considered and was of interest. The oxidation pond is one method, recycle another. Treatment is practicable as noted in the references 25, 26, 27 and could be employed at the Orange County site.

Sampling and Analysis. In order to define what is happening, sampling and analysis techniques must be adequate. Sampling procedures were mentioned in a number of references.[5,10,11] These procedures were extracted and furnished to personnel involved as appropriate. Sampling for chemical and biological analyses were standardized based on the well pumping and vacuum system described elsewhere. Analyses for complex organics and microbiological contamination are described separately herein. The available literature, with the exception of one article by Steiner and Fungaroli,[28] provided little reference to these types of analyses. Instead, most reports were concerned with such parameters as pH, hardness, ionic concentrations, and gross parameters of COD and BOD.

Distribution of Leachate. The landfill area is underlain by impervious material covering the Floridan aquifer which is under pressure; therefore, leachate migration from the landfill operation is of interest. The literature consulted and referenced indicates horizontal movement of contaminants should occur and that little vertical diffusion could be expected.[2,4] So, vertical mixing was not anticipated. Therefore, contaminant distribution should be restricted to the upper layer of soil at the Orange County site. This was anticipated in the planning for the sampling wells. Initial wells, with the exception of aquifer wells, were 30 feet deep, or less. Some of the later wells were in three-well clusters at varying depths. This arrangement permitted a comparative determination of the water quality at various depths within a relatively small area subject to availability of data. Additionally, percolation of leachate to the site drainage ditches was expected. Hence, surface quality monitoring was important along with well sampling.

Water Quality Monitoring Program

The demonstration of satisfactory solutions to problems inherent in the sanitary landfill disposal of solid waste in an area with a high water table was an overall project objective. Realizing that potential contamination of the surface and ground water in the general area of the landfill operation would be a particular problem, the Orange County Pollution Control Department was requested to obtain necessary background information and to conduct periodic sampling of surface and ground waters throughout the project period to ascertain whether pollution problems did occur.

Related objectives for the Demonstration Project, which are concerned with water pollution control, suggest that there be means of

> . . . supplying local, state and Federal pollution control agencies with data on water pollution problems as well as solutions to water pollution problems stemming from a high water table landfill operation.

. . . investigating and reporting changes within the "demonstration" and "control" landfill areas for variants in physical, chemical (organic and inorganic), and microbial activity in the aqueous environment.

To accomplish these objectives, a comprehensive monitoring program was established to test changes in ground and surface water quality including bacteriological, biological and inorganic-organic chemical parameters. The study team designated to investigate these parameters included professionals from the Orange County Pollution Control Department, Florida Technological University, and VTN INC. In support of these investigations, grant funds were available for hiring additional staff to analyze biological and chemical samples; to obtain chemical and bacterial samples; and to oversee construction of the shallow and deep well field.

The Orange County Pollution Control Department provided the overall direction in the field surveillance program by developing a sampling program for both ground and surface waters. The Pollution Control Department has a complete chemical and biological laboratory. An enlargement of these facilities provided space for handling an increased volume of sample analysis and accommodated a new microbiology laboratory. The chemical laboratory had one chemist, one technologist, and one laboratory aide. The biological laboratory employed one biologist, one technologist, one technician and one aide. The microbiological laboratory employed one microbiologist and one technologist. In addition, the project provided one biologist, one chemical technologist, and one biological technician to the laboratory staff.

Prior to beginning landfill operations, a comprehensive ground and surface water evaluation was completed for the project area. The sampling network provided the required natural baseline data for network comparison with subsequent water quality monitoring activities. The sampling network included

. . a surface water biological sampling schedule and station locations developed to insure sampling of the solid waste disposal site, outfall canal, and the receiving stream (Little Econlockhatchee River) above and below the confluence of the outfall canal.

. . a surface water chemical sampling schedule and station locations developed for the holding pond, effluent, outfall canal, and receiving stream, described previously.

. . a network of shallow wells and deep wells--within and adjacent to the landfill--developed under the direction of the consulting geologist responsible for ground water management studies.

Surface Water Studies. The study of the quality of the surface water included the establishment of sampling locations and schedules; sampling methods; selection of pertinent physical, chemical, and biological analyses; and the interpretation of the collected data. In the following pages, these elements of the study are discussed in detail.

Sampling Locations. Surface monitoring for this study includes: (1) the demonstration site's pond, (2) the 2.7 mile outfall canal leading from the Demonstration Project and (3) a 14.8 mile length of the Little Econlockhatchee River, the receiving stream. The three major factors basic to the location of sampling stations along the river were

. . . the existence of two areas of domestic waste effluent discharge.

. . . the varying morphological characteristics.

. . . the availability of chemical and phytoplankton data previously obtained by the Orange County Pollution Control Department.

With the above stated factors in mind, twelve stations were established for the initial background study (see Figure 28 and Table 2). Of these stations, nine were for chemical and biological monitoring and three for chemical monitoring only. Two of these stations were located in the outfall canal (Stations 1 and 2) and one station was in a tributary of the river (Station 4). The remaining were established along the entire length of the river (Stations 3, and 5 through 9).

Some alterations were made to the above during the second project year due to additional excavation of the demonstration site drainage system, canalization efforts for the tributary stream, and coordination of biological and chemical stations. These adjustments required the addition of one station each in the demonstration site's pond (Station Pond A) and its effluent (Station Pond Effluent), the temporary elimination of Station 4, and the consolidation of Stations 5 and 5A, 6 and 6A, and 7 and 7A.

Sampling Methods. Water samples for physical and chemical analysis were originally (through May 1971) obtained using a 24 hour battery operated composite sampler developed by the Orange County Pollution Control Department (Figure 29). Since that time, the samples were obtained by submerging an acid washed, dark, polyethylene container six to twelve inches below the surface of the water. Samples for organic analysis were obtained in the same manner using clear, ground glass stoppered bottles. All samples were immediately placed in a cooler for transporting to the laboratory.

Aquatic macroinvertebrates were collected using two methods of sampling. Qualitative samples were taken with a dip net and quantitative samples were obtained using an artificial substrate. The method employing an artificial substrate utilized multiple-plate samplers constructed with some modifications from that of Hester and Dendy[29] (Figure 30). Each sampler consisted of one-quarter inch thick Masonite plates and spacers. The eight plates were eight centimeters square and were separated by two centimeter square spacers. Each multiple-plate sampler was held together by a six-inch eyebolt. At each station, two samplers were then submerged approximately one foot below the water surface and two feet apart. At the end of the four-week period, the samplers were removed, placed in separate plastic bags in a cooler and transported to the laboratory for examination.

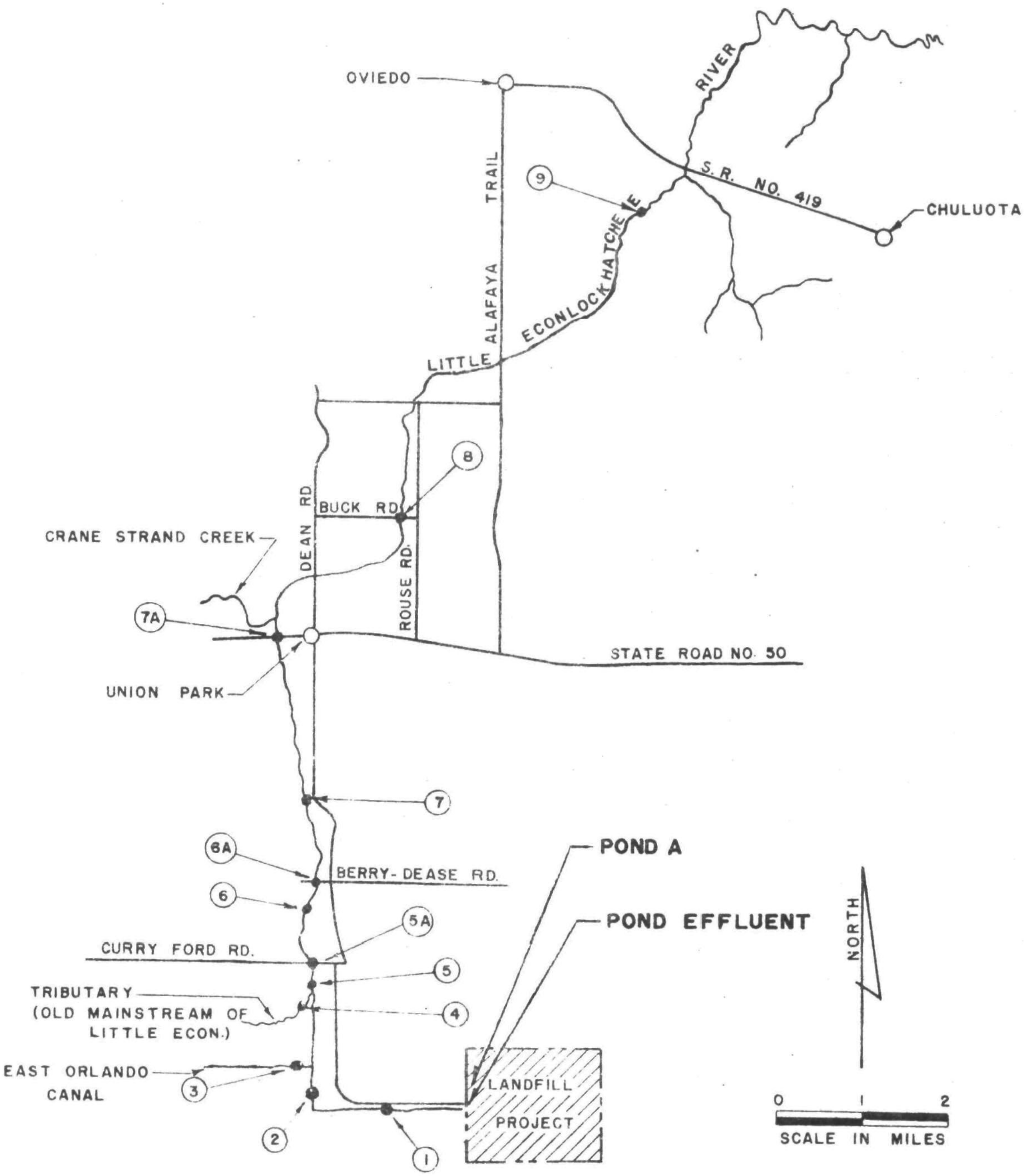

FIGURE 28 Location Of Surface Water Sampling Points, Orange County Demonstration Project.

TABLE 2

SUMMARY OF SURFACE WATER SAMPLING STATIONS

Station Number	Type	Location
Pond A	Chemical & Biological	Located on the northeast section of Pond A.
Pond Effluent	Chemical	Located just after the Pond A water enters the canal.
1	Chemical & Biological	Midway along westerly portion of the outfall canal, approximately one mile from the landfill.
2	Chemical & Biological	Downstream from Station 1, midway along northerly portion of the outfall canal, approximately two and one half miles from the landfill.
3	Chemical & Biological	Channelized portion of the Little Econlockhatchee· One fourth mile upstream from the outfall canal within and downstream from an area of domestic waste effluent.
4	Chemical & Biological	Tributary of the Little Econlockhatchee River before channelization took place, this was the Little Econlockhatchee River proper (it enters the canalized portion of the river approximately three and one fourth miles from the landfill). Temporarily discontinued due to land clearing for canalization.
5	Chemical & Biological	Channelized portion of the river three and one half miles from the landfill and downstream from the tributary (Station 4).
5A	Chemical	Channelized area at Curry Ford Road four miles downstream from the landfill.*
6	Chemical & Biological	Natural stream area with a broad natural flood plain, approximately four and three fourth miles downstream.
6A	Chemical	At USGS sampling station, five miles downstream from the landfill off Berry-Deese Road.*
7	Chemical & Biological	Natural stream area with a broad natural flood plain six miles from the landfill.

TABLE 2 (CONTINUED)

SUMMARY OF SURFACE WATER SAMPLING STATIONS

Station Number	Type	Location
7A	Chemical	At Highway 50 in Union Park Approximately eight miles from the landfill and just upstream from an area of domestic waste discharge *
8	Chemical & Biological	Located at Buck Road approximately ten and one half miles downstream from the landfill This area has a natural broad flood plain
9	Chemical & Biological	Natural flood plain area at Tanner Road in Seminole County, located approximately sixteen miles from the landfill and just prior to confluence with the Big Econlockhatchee River

*Discontinued in 1971

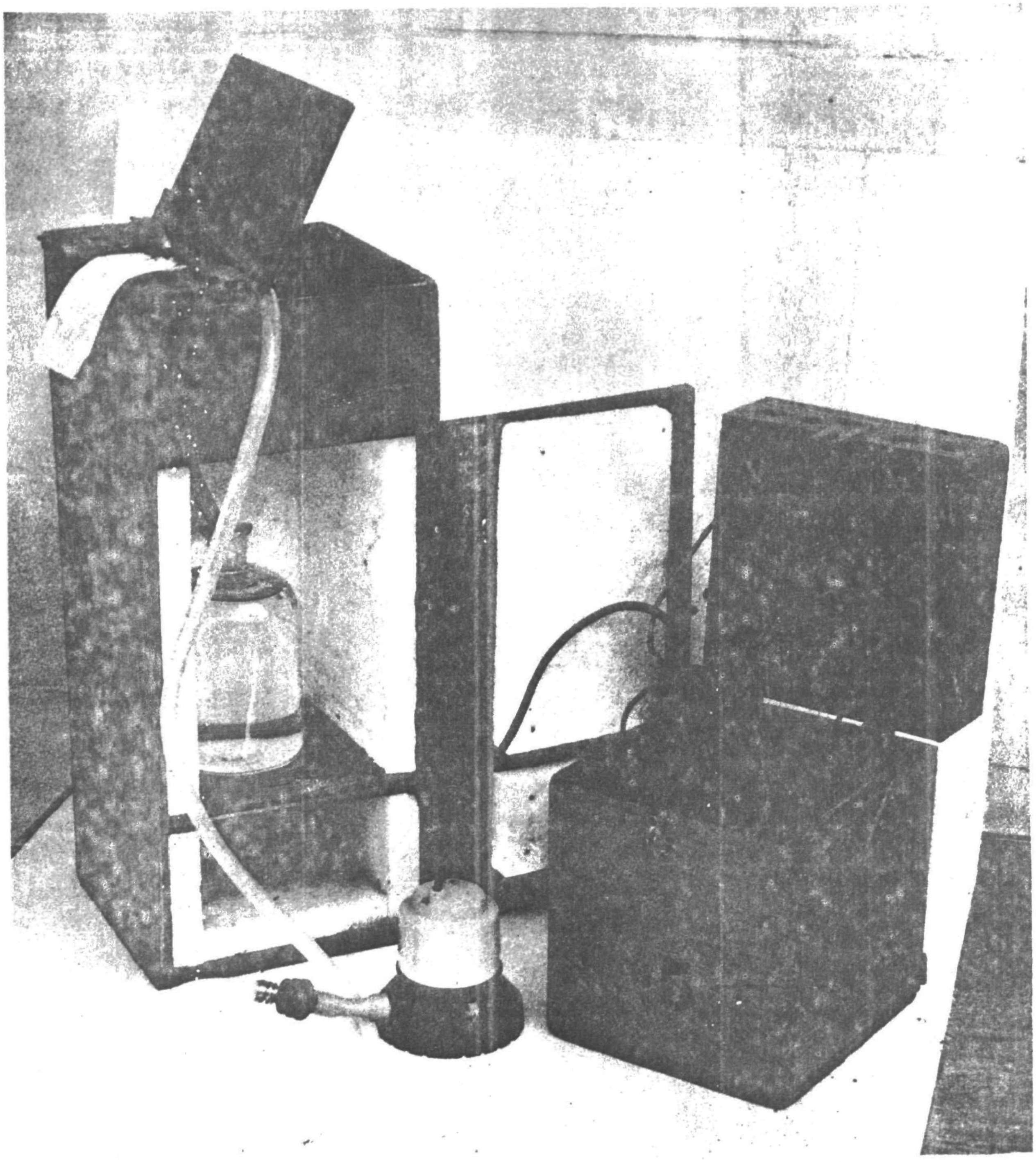

FIGURE 29. 24-Hour Composite Sampler for Surface Water Sampling.

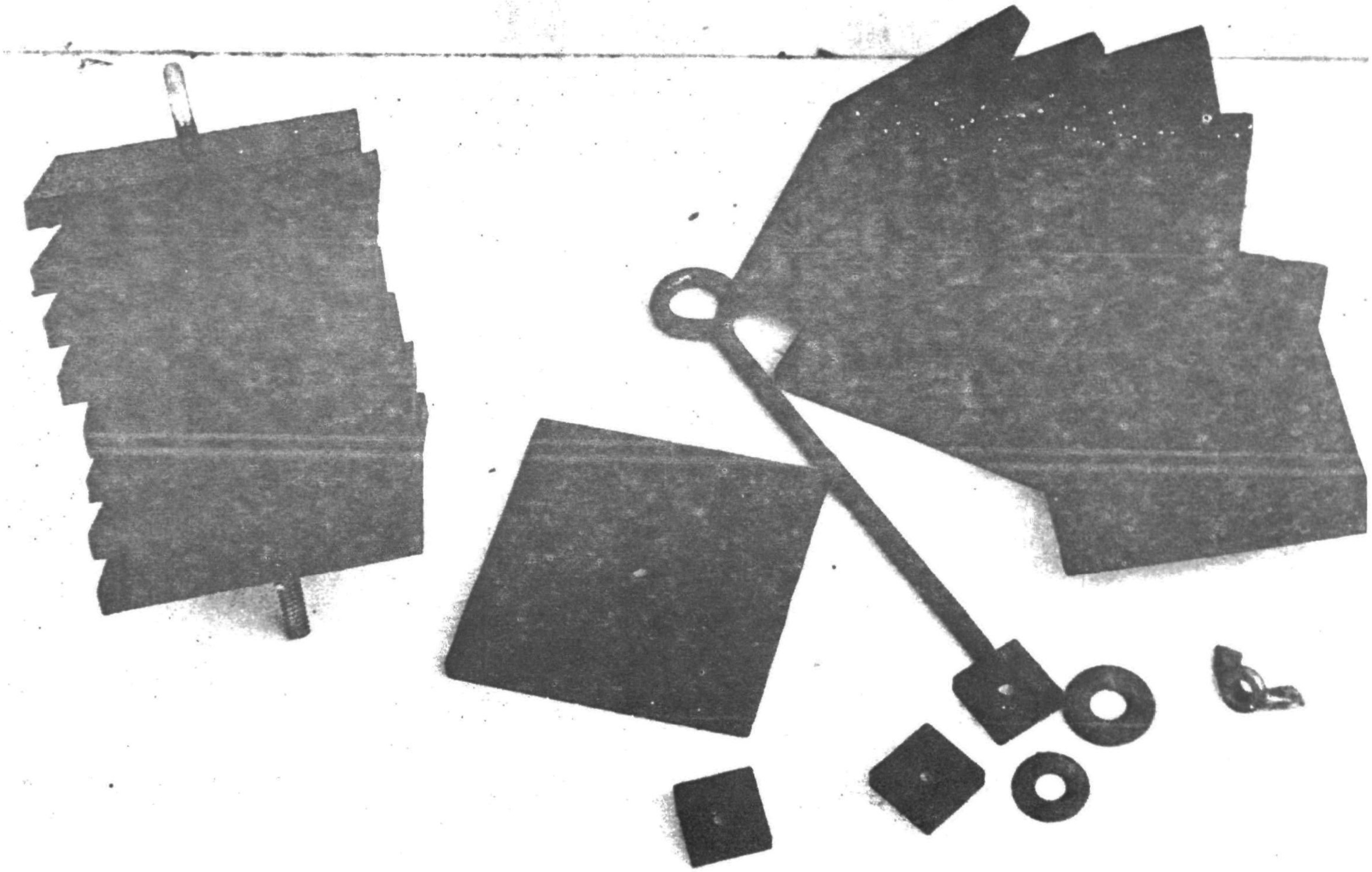

FIGURE 30. Multiple-Plate Macroinvertebrate Sampler.

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Qualitative, macroinvertebrate samples were obtained by sweeping a D-framed collection net across the bottom deposits and through aquatic vegetation. With an attempt to collect at least one of every species present, the organisms were sorted in the field using a white porcelain pan and forceps and placed in vials of 95 percent ethanol. All the various natural substrates in a station area were investigated.

Phytoplankton samples were obtained by submerging a gallon container six to twelve inches below the surface of the water. The samples were then placed in a cooler for transporting to the laboratory.

A periphyton sampler was constructed for each station following the basic design of Weber[30] (Figure 31). Each sampler contained eight, one by three inch microscope slides which were submerged three inches below the water surface. At each station after the slides had been submerged for six weeks, four slides were removed and placed in a jar containing 100 milliliters of five percent formalin solution. The remaining four slides were placed in 100 milliliters of 90 percent aqueous acetone. All jars were refrigerated in coolers for transferring to the laboratory.

Sampling Schedule. Samples for physical and inorganic chemical analyses were taken four times during the first month and every three months thereafter until May 1971. At that time monthly sampling began at all stations, excluding Stations 6 through 9, which continued on a quarterly basis. Since February 1973, efforts were restricted more to the demonstration site drainage system by retaining Stations PA, PE and 1 on a monthly basis and restricting all others to a semiannual sampling schedule. Samples for organic studies were taken monthly from Stations PA, PE and 1.

Biological samples were taken regularly but on a more limited overall schedule. Phytoplankton samples were obtained on a monthly schedule from all stations excluding Stations 6 through 9. These remaining four stations were sampled quarterly. Since May 1971, sampling days were in conjuction with water samples for physical and chemical analyses. Periphyton, initially sampled continuously (through May 1971), is now on a semiannual schedule for all stations. Macroinvertebrate sampling by both qualitative and quantitative methods was on a monthly basis until May 1971 when the multi-plate method was changed to semiannual sampling. Samples for microbial studies were taken monthly from Stations PA, PE, and 1.

Physical, Chemical and Biological Analyses. The monitoring program for evaluating the surface water quality included pH (laboratory and field), chlorides, sulfate, sulfide, chemical oxygen demand, dissolved oxygen, phosphate (total and ortho), nitrogen (nitrate, nitrite, ammonia and organic), temperature, conductivity, turbidity, solids (total, suspended, and dissolved), calcium, magnesium, iron, aluminum, zinc, potassium, sodium, copper, methylene blue active substances and carbon (total organic and inorganic) (Volume II, Tables 1 through 7). Sulfate, field pH and chemical oxygen demand analyses were not performed during the first year of the project. Analytical methods are presented in the Appendix.

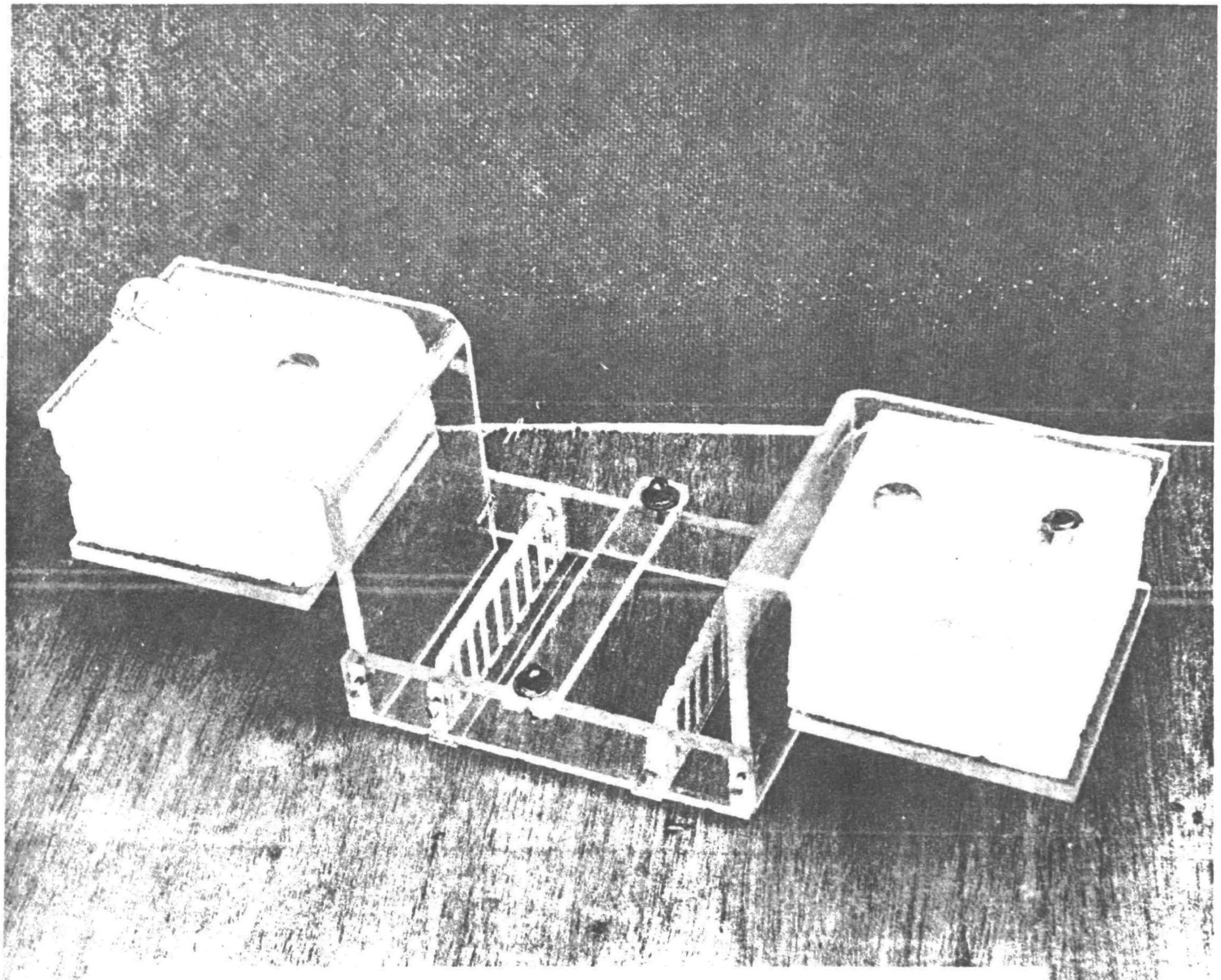

FIGURE 31. Periphyton Sampler for Surface Water Analysis.

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Biological monitoring included cell counts, identification, and pigment analysis of both planktonic (Volume II, Tables 8 and 9) and periphytic (Volume II, Tables 10 and 11) algae. The macroinvertebrate community was evaluated from identifications and numbers present (Volume II, Tables 12 through 15). Microbiological analyses included viable counts of aerobes, anaerobes, sulfur oxidizing and sulfur reducing bacteria, as well as fungi (Volume II, Table 17). Identification of genera and species and specific organisms complemented data on counts. Fecal coliform counts, *Salmonella* and *Staphylococcus* selection procedures were followed to search for possible contamination with pathogens.

Little Econlockhatchee River - Physical and Chemical Properties. The Little Econlockhatchee River (Stations 3, and 5 through 9) and one of its tributaries (Station 4) was monitored for water quality beginning October 1970. Since the landfill drainage system entered the river between Stations 3 and 5, it was important to obtain data to evaluate the river's present condition. The following is a summary of the physical and chemical properties of the receiving water.

Since the river is shallow with varying degrees of cover, considerable water temperature variations were expected along its length. The water temperature ranged from 10C to 30C throughout the study. The water temperatures in the canals and below the reservoir near Union Park were often higher than those in sections of the river having a forest cover.

True color was not determined during the study although field notes and observations after filtrations indicated high color from dissolved organic material typical of the lowland drainage systems. Turbidity averaged from 6.7 to 25.6 JTU throughout the river with the higher turbidities in the canalized areas. The turbidity values are a product of biotic and abiotic material. The latter type of material was especially present during the initial excavation of the landfill drainage system. Subsequent diking and changes in excavation procedures prevented a recurrence of the problem. Suspended solids reflected the same variation in different locations with the higher values occurring in the canalized areas and the lowest at stations most distantly downstream from disturbed areas (Stations 7 and 9). Volatilization of the suspended fraction indicated 50 to 70 percent was inorganic material.

Total nitrogen concentrations at each station averaged from 1.69 to 10.90 milligrams per liter, with the higher values downstream from Station 7. According to location, there was a variation in the organic portion (0.8 to 2.6 milligrams per liter as nitrogen); however, the most extensive variations occurred in the organic nitrogen (0.37 to 6.45 milligrams per liter). The various forms of the inorganic nitrogen (nitrate, nitrite, and ammonia) indicated an increase in the more reduced forms and a decrease in the oxidized form after Station 7. Total phosphate concentrations in the river are high and display a trend similar to total nitrogen. Averaged phosphate values ranged from 1.04 to 4.22 milligrams per liter as phosphorus. The ortho-phosphate concentrations (65 to 97 percent of total phosphate) ranged from 0.68 to 3.69 milligrams per liter as phosphorus. In comparing these two nutrients (nitrogen and phosphate) there is a substantial excess of phosphorus throughout the river. An addition of nitrogen to the system would result in a further deterioration of the river.

Average dissolved oxygen concentrations ranged from 2.9 to 4.7 milligrams per liter. Seasonal variations were most evident in the canalized areas where supersaturation was observed during optimum conditions for primary productivity. However, averaged saturation percentages ranged from 31 to 52 percent (Station 8 and 6, respectively.). Biochemical oxygen demand averages were highest at Stations 3, 8 and 9 while chemical oxygen demand displayed very little spatial variation throughout the river (37 to 56 milligrams per liter).

The river had a circumneutral pH level with averages ranging from 6.8 to 7.3. The total alkalinity as calcium carbonate averages from 41 to 52 milligrams per liter upstream from Station 8, while average values from Stations 8 and 9 were 101 and 89 milligrams per liter, respectively. Acidity concentrations as calcium carbonate range from 12 to 23 milligrams per liter with highest values occurring in the canalized areas.

Variation of electrolytes in the river was evident with average conductivity ranging from 199 to 227 micromhos per centimeter upstream from Station 8, while at that station and downstream the averages exceeded 400 micromhos per centimeter. This same trend was evident, but not as pronounced in total dissolved solids and total hardness, where the range of average concentrations was 147 to 226 and 40 to 64 milligrams per liter, respectively. The higher concentrations were characteristic of Stations 8 and 9.

Of the two major alkaline earths, calcium and magnesium, the former was found to have the highest concentrations throughout the river. Calcium and magnesium averages for each station ranged from 9.17 to 16.7 and 2.9 to 5.1 milligrams per liter, respectively. Concentrations of calcium were typically 3.1 to 3.4 times those of magnesium at each station. The alkalies, sodium and potassium, had concentration averages ranging from 13.6 to 25.6 and 1.9 to 5.8 milligrams per liter, respectively. The highest concentrations of each of these major ions were found at Stations 8 and 9.

Averaged concentrations of iron varied from 0.3 to 0.6 milligrams per liter with highest concentrations located in the canalized area and gradually decreasing downstream. A similar trend was found for aluminum; the range was between 0.18 and 0.85 milligrams per liter with the highest average at Station 7 (only slightly higher than upstream) and the lowest found at Station 9. Copper was found to average no higher than 0.014 milligrams per liter at any station and no one station was significantly different from the others. The average concentrations of zinc ranged from 0.02 to 0.07 milligrams per liter with the higher values at Stations 8 and 9.

Average concentrations of chlorides at each river station ranged from 20 to 38 milligrams per liter. The ratio of chlorides to sodium indicated an excess of chlorides when compared to the theoretical ratio of sodium chloride. The highest concentrations were found at Stations 8 and 9.

Little Econlockhatchee River - Biological Properties. Aquatic weeds (macrophytes), attached algae (periphyton), free-floating algae (phytoplankton) and macroscopic aquatic invertebrates (macroinvertebrates) were monitored. For purposes of this study, the description of each of these communities is limited to the establishment of baseline characteristics for use in detecting any changes in water quality.

The macrophyte community of the Little Econlockhatchee River was not investigated either quantitatively or qualitatively. However, some discussion is pertinent to the description of the stream. With a constant supply of water abundant in nutrients and the absence of the natural floodplain cover, the canalized stations (Stations 3 and 5) had dense stands of the submerged Florida Elodea *(Hydrilla verticillata)* and the floating water-hyacinth *(Eichornia crassipes)*. Often in quiet waters, or during low flow, duck weed *(Lemna minor)* covered the water's surface not occupied by *Eichornia*. There was usually a "stream" within the canal where the flow was concentrated due to the surrounding density of *Hydrilla*. Although these plants assimilate nutrients for growth, their death (either natural or by periodic herbicide applications) and subsequent decomposition causes a release of the nutrients back into the stream system. Between Stations 7 and 8 is a reservoir which displays similar aquatic weed problems.

Downstream from these canalized areas were morphologically unaltered sections of the river (Stations 6, 7, 8 and 9). The macrophyte community there bore no resemblance to the upstream area. The floodplain remained in its natural state allowing the stream to meander through a swamp forest (Stations 6 and 7) and a floodplain forest (Stations 8 and 9). The areas provided the humic acids and the shading of the stream. Macrophytes were very limited here and did not include those found in the canal.

The standing crop of periphytic algae showed both locational and seasonal variations throughout the stream. A locational comparison indicates higher standing crops at Stations 3 and 8. At each of these two stations there was an average of over 1,000 cells per square millimeter and average pigment content of over 50 milligrams of Chlorophyll-a per square meter. The lowest standing crops were found at Stations 6 and 7 where average Chlorophyll-a values and cell counts were below 10 milligrams per square meter and 200 cells per square millimeter, respectively. This reflected an approximate 500 percent increase in the periphyton standing crop at the two stations downstream of domestic waste treatment facilities as compared to the two stations showing partial recovery. The ratios of cell counts to Chlorophyll-a were lower than those found in the landfill drainage system with an exception of the station in the undisturbed tributary (Station 4). Although there was no quantitative correlation between cell counts and Chlorophyll-a concentrations, this ratio pattern proved interesting in not only the periphyton studies but also the phytoplankton monitoring.

Seasonal variations in the periphyton standing crop were more apparent than the seasonal changes in composition. The standing crop increased in late winter with typical maximums in spring. This seasonal pattern, depending on the species involved, could be generally attributable to water temperature, flow rate, chemical composition, and deciduous cover. More detailed evaluation of this was not within the scope of this monitoring program.

The species composition of the periphyton community was primarily dominated by diatoms (Bacillariophyceae), although over 40 genera found in the sampling program were in other phyla and classes. Permanent slides of diatoms from each sample were prepared for future baseline studies of this important community. Available data indicated *Fragillaria* was most ubiquitous to the stream; *Cocconeis* was limited to the cleanest stations (Stations 4, 6 and 7) and *Melosira* was found most abundantly in the canalized areas (Stations 3 and 5). Genera in other phyla which were often dominant are *Coelastrum* (Stations 7 and 9), *Geminella* (Station 8), and *Stigeclonium* (Station 5). When considering the non-diatom genera most commonly occurring in the stream, all genera are associated with the meso-saprobic zone of the saprobian system of stream pollution classifications. These genera are *Stigeclonium, Chlorella, Euglena, Closterium, Cosmarium, Phacus,* and *Scenedesmus.*

The standing crop of planktonic algae in a stream is a product of the periphitic forms washed from their substrate and the plankton of backwaters. Phytoplankton variations in the river displayed similarities to the periphyton community discussed above. The highest standing crop occurred at Stations 3 and 8 where average pigment concentrations were approximately 50 milligrams of Chlorophyll-a per cubic meter and algal counts averaged approximately 1200 algae per milliliter. These two stations were in sharp contrast with Stations 6 and 7 where the phytoplankton standing crop average values were 10 milligrams of Chlorophyll-a per cubic meter and 200 algae per milliliter. Although these numerical values are similar to those of the periphyton standing crop discussed previously, the periphyton actually represents a much greater total standing crop when the area of available substrate and the river volume are considered. The ratios of algal counts to Chlorophyll-a in the river were lower than those found in the landfill drainage system and in an undisturbed tributary of the river (Station 4).

Seasonal variations in the phytoplankton standing crop are unlike those of the periphyton. The standing crop increased in the spring and reached a maximum during the summer. A decline followed in the fall and winter. This seasonal trend is a reversal of the conditions found in the periphyton monitoring program. There were no major seasonal variations in the standing crop upstream from the reservoir and in the morphologically undisturbed portion of the river. Changes in this area appeared to correspond to minor variations of phytoplankton found in the upstream canalized portion of the river.

The dominant species found in the plankton samples of the river also varied seasonally and depended on location. In the canalized area (Stations 3 and 5) pennate and centric diatoms dominated in the winter and spring with the addition of *Ankistrodesmus falcatus* in the latter season. *Cyclotella, Scenedesmus quadricauda* and *Agmenellum* were dominant in the summer followed by the typical winter community and *Chlamydamonas* in the fall. Downstream at Stations 6 and 7 pennates and *Euglena* dominated during the winter with loss of the *Euglena* population during the spring. *Agmenellum* dominated in summer followed by an increase in *Euglenophyceae* and pennate diatoms in the fall. The stations located after the waste treatment facilities and reservoir (Stations 8 and 9) were significantly different. In this area, *Scenedesmus quadricauda* dominated throughout the year with the inclusion of *Chlorella, Ankistrodesmus falcatus* and *Chlamydamonas* in the spring and *Euglena* in the summer. Fall months were similar to the spring communities with the exclusion of *Ankistrodesmus.*

The macroinvertebrate communities of the Little Econlockhatchee River varied in size, diversity and species composition. Seasonal comparison of total counts revealed an average of 300 to 500 organisms per square meter in the canalized headwaters. The community size increased downstream through the undisturbed area to an average of 1600 organisms per square meter at Station 7. Downstream from this station, the river received numerous domestic waste treatment plant effluents which resulted in an increase of the average total count to 4500 organisms per square meter. The average total count decreases downstream to 2700 organisms per square meter at Station 9. Species diversity and Biotic Index values also revealed variations at each station. Station 7 has the highest species diversity and the highest Biotic Index. Upstream from here, the diversity is good, although the Biotic Index indicates the species present are pollution tolerant. In contrast, the downstream stations (Stations 8 and 9) revealed a depressed diversity and Biotic Index with a partial recovery at Station 9. When considering species composition, Stations 6 and 7 had a greater percentage of pollution intolerant species and a corresponding decrease in pollution tolerant species than the other stations of the river. In these two areas and other stations located in morphologically unaltered areas, there was a greater occurrence of rheophilic organisms in contrast to the greater occurrence of lentic forms found in the canalized sections.

Seasonal variations in total counts displayed peaks occurring in early spring, midsummer and winter. Other stations displayed similar trends. The general trend was similar to that of the periphyton excluding the additional increase in summer. These seasonal variations in total counts could have been due to characteristic life cycles, retention of organisms during low flow, availability of food, and deposition of drift organisms during fluctuating high river flow conditions.

Site Drainage System - Physical and Chemical Properties. The landfill drainage system monitoring program included Pond A, the Pond A Effluent, and Stations 1 and 2 along the outfall canal leading to the Little Econlockhatchee River. Monitoring for baseline data and water quality determinations began in October 1970.

Data for the pH values of surface waters are presented in Volume II, Table 4. Values are reported for the initial pH of water samples and the final pH after one hour of vigorous aeration with carbon dioxide-free air. This aeration procedure was instituted after it was discovered that the pH of certain water samples (particularly ground waters) varied considerably due to varying concentrations of volatile acidic materials,[31] such as carbon dioxide and hydrogen sulfide. The observed increase in pH can be correlated with amount of carbon dioxide and hydrogen sulfide initially present in the sample. Separate analyses for hydrogen sulfide content of these waters showed that practically none was present; therefore, any increases in pH after aeration were primarily due to a decrease in carbon dioxide. If one compares the pH data with those obtained for alkalinity and acidity, it becomes obvious that a close correlation exists among these data.

In general, the surface waters of the landfill site tend to be acidic. The average pH of the canal draining the site over the study period was 5.41 with a range from 3.85 to 7.1. The increased acidity of the canal waters (Station 1) could be correlated with periods of heavy rainfall. A case in point is a pH value of 3.85 obtained on September 26, 1972. Rainfall data from the site show that daily rainfalls in excess of 1/2 inch had occurred for 9 out of the preceding 20 days and that on October 20, a total of 2.29 inches of precipitation had fallen. These heavy October rains followed a very dry September during which there had only been 0.85 inches of precipitation. On-site observations showed that a large volume of water from adjacent Bay Branch Swamp flowed into the canal. The canal waters also exhibited the reddish-brown color (examined also by spectral analysis), organic carbon content, and inorganic properties of water found in peat bogs.

The pH values, color, and carbon content of Pond A and its effluent remained fairly stable over the month of October 1972, being relatively unaffected by the heavy rainfall. The above data, coupled with that obtained from the canal, showed that heavy rainfall and resulting runoff of acidic, organic laden water from adjacent woodlands was the primary reason for pH changes observed at Station 1 during the period of the study. In no instance can any changes in pH of the surface waters be attributed directly to the landfill site itself. Schnitzer and Dejardins[32] have shown that a natural soil leachate from a Newfoundland humic podzol possessed properties similar to those of the leachate from woodland soils of the Orange County Solid Waste Disposal Site. The observed low pH of the woodland leachate can be attributed primarily to carbonyl groups of fulvic acids.[31]

In July 1972 the pH of Pond A, its effluent and Station 1 of the drainage canal were more basic prior to, than after, aeration. This would imply the presence of a volatile basic material. The fact that the pH of all three water samples was more acidic after aeration than it normally would have been (normally these bodies of water have a pH of about 6.5 to 6.7 after aeration) tended to indicate a profound alteration in water chemistry. A possibility is that the algal bloom observed at that time caused a depletion of carbon dioxide as well as certain other ions resulting in pronounced chemical changes.

The pH of Pond A water was fairly constant over the period of the study, with an average value of 6.29 and a range from 5.16 to 7.35. The effluent from Pond A was more acidic than the pond itself, having an average pH of 5.99 and a range from 5.10 to 7.00.

The same situation occurred in March 1973 that had previously been recorded in July 1972. The waters from Pond A and its effluent were found to be more acidic after than prior to aeration. The canal waters at Station 2 did not show a similar pattern; so one can conclude that the factors which caused the observed alkalinity were not present in the drainage canal. It is possible the algal bloom and the resulting depletion of cations and carbon dioxide in these waters can explain the results obtained. Overall the extremely soft water condition in Pond A provided the water with very little buffering capacity and therefore permitted more drastic pH changes.

The soft water condition in Pond A is exemplified by the average total hardness and alkalinity concentrations of 5 and 7 milligrams per liter, respectively. Downstream at Station 2, hardness and alkalinity averaged 24 and 42 milligrams per liter, respectively, indicating the increased mineralization and buffering capacity. The components of the total hardness values did not increase proportionally from Pond A through Station 1. Calcium and iron increased in greater proportions than did magnesium, aluminum, and zinc. Copper was very seldom detected. When present, a concentration greater than 0.04 milligrams per liter was unusual.

The chloride concentrations averaged 12 milligrams per liter in Pond A and its effluent with higher averages (17 and 19 milligrams per liter) downstream. The atomic ratio of sodium and chloride was almost unity and their concentration ratio almost equaled that of seawater and rainwater. The chloride concentrations here were expected when considering the relatively short distance from the ocean and its subsequent influence on the salt concentration of the rainwater. The conductivity was higher at the downstream stations (143 micromhos per centimeter) as compared to Pond A (75 micromhos per centimeter). Although this measurement does not indicate what ionic substances were present, it does fluctuate with regard to their concentrations and is therefore indicative of the total salt concentration.

Phosphate levels were typically below 0.1 milligrams per liter with varying proportions of the ortho-phosphate form. Organic nitrogen was usually less than 1 milligram per liter in Pond A and its effluent, but it was often higher at Stations 1 and 2. Other nitrogen forms had the same trends with Pond A and the pond effluent having smaller concentrations than the two downstream stations. The concentrations of these nutrients were high enough to produce larger algal populations than noted previously. The ratio of nitrogen to phosphates indicated an excess of nitrogen for optimum algal growth. The low carbon dioxide values (below 1 milligram per liter) found in Pond A indicated the availability of carbon as a possible limiting factor in the algal populations.

The dissolved oxygen content averaged 6.6 milligrams per liter and 73 percent saturation. With this oxygen concentration from samples obtained in the mornings, the biological productions of oxygen appeared to be sufficient to satisfy any pressures that the natural chemical oxygen demand (32 milligrams per liter) and biochemical oxygen demand (5.5 milligrams per liter) may have exerted on the pond system. Downstream in the outfall canal the oxygen content and biochemical oxygen demand were typically lower while the chemical oxygen demand was higher. Due to the large organic deposits in the adjacent swamps, the presence of this natural chemical oxygen demand concentration is common to this area.

Table 3, Volume II, presents data obtained for the sulfide content of surface waters during the course of this study. It is apparent that the sulfide contents of Pond A, its outfall and the canal at Station 1 have been very low throughout the course of this study with one exception. The sulfide concentration of all three surface water sites increased to about 4 milligrams per liter in July 1972. The sulfate concentrations also increased through the summer from values usually below 5 milligrams per liter to a high value of about 20 milligrams per liter.

Data for methylene blue active substances were included as a measure of linear alkyl sulfonates. The method is far from specific, being subject to many interferences, both positive and negative, but data obtained by this method show that no pollution of surface waters with detergents has occurred during the course of this study. Results are shown in Table 7, Volume II.

The carbon content of both Pond A and its effluent remained quite low throughout the course of the study. Pond A has contained an average of only 15.8 milligrams per liter total carbon over the period of this study of which an average of 12.9 milligrams per liter was in the form of organic carbon. On an average, only 2.5 milligrams per liter of inorganic carbon was present in Pond A and the majority of this was present as carbonate carbon (i.e., not volatilized by aerating with CO_2 free air). The organic carbon rose to a high of 23.2 milligrams per liter in July of 1972, while the carbonate carbon fell to zero. The carbon content fluctuated about the mean of 12 to 13 milligrams per liter at all other times. One might note the unusual pH changes were concurrent with the high organic carbon concentration.

The effluent from Pond A showed a pattern almost identical to that of the Pond itself with respect to all major forms of carbon. The effluent showed the same rise in organic carbon in July 1972.

The carbon content of the canal waters at Station 1 were much more variable than those of Pond A and its outfall - varying from a low of 19 to 71 milligrams per liter total carbon. The majority of the carbon present in these low pH waters was in the organic state. The amount of carbon present in the canal waters appeared to be correlated with rainfall and the subsequent leaching or direct runoff from adjacent swamp land. Samples of water from Station 1 were freeze dried and the resulting brownish powders were extracted with various solvents and the extract analyzed by gas chromatography. Only non-volatile, high molecular weight compounds were found to be present. These compounds appear to be made up almost exclusively of humic and fulvic acids,[33] particularly the latter, as it is more soluble in acidic media.[32,34]

Samples of canal water collected in January 1972 were lyophilized and the resulting brown solids were dissolved in aqueous solutions of pH 1.0 and 13.0. As expected, the dissolved solids present in the canal waters were more soluble in acid than in base and sephadex column chromatography[35] showed the acid soluble fraction to consist of a low molecular weight component (about 1,000 molecular weight) which had an absorption spectrum similar to that of fulvic acid. Schnitzer and Desjardins[32] found that 87 percent of the dry, ash-free weight of a natural soil leachate consisted of fulvic acid which has an average molecular weight of 670 and an elementary composition of $C_2OH_{12}(COOH)_6(OH)_5(CO_2)_2$. The observed acidity of their leachate (pH of 3.9) was attributed almost entirely to carboxyl groupings, although a small amount stemmed from phenolic hydroxyls. Based on the data, it can be concluded the majority of the dissolved organic matter present in the canal at Station 1 was composed largely of fulvic acids and related humic materials. It might be noted that these compounds are excellent chelating agents and were found to mobilize and transport large amounts of metals through soil water; particularly silica, aluminum, and iron.

That fraction of lyophilized organic matter from Station 1 soluble at pH 13.0 was found, in general, to be of a higher molecular weight than the acid soluble fraction and, in contrast to the acid soluble fraction ion, consisted of two molecular weight fractions. One of these fractions had a molecular weight of over 10,000 while the other was greater than 1,000 but less than 10,000. The over 10,000 molecular weight material was present in very small quantities while the lower molecular weight fraction accounted for the majority of the organic matter solubilized by 0.1 normal potassium hydroxide.

The above observations tend to confirm that the major organic material found in the canal waters was acid-soluble fulvic acid which had been leached from surrounding native soils. It was noted that when the pH of samples of canal water was adjusted with a strong base to values of 10 or greater, that a yellow-brown flocculate would appear, followed by clearing of the water.

Site Drainage System - Biological Properties. The biological monitoring program for the landfill pond and outfall canal included phytoplankton, periphyton, microinvertebrates and microbiological characteristics. The results of these studies are provided in the following discussion.

The phytoplankton standing crop was typically larger in Pond A than in the outfall canal. A seasonal pattern in Pond A was found to have submaximums in late fall, early winter and early spring, with maximums in midsummer. In the outfall canal only the summer maximums were evident. Chlorophyll-a concentrations reflected the same seasonal variations. Algal counts ranged from 40 to 600 algae per milliliter throughout the drainage system. Chlorophyll-a concentrations ranged from 0.5 to 22.7 milligrams per cubic meter. Total algal counts in excess of 500 algae per milliliter and Chlorophyll-a concentrations in excess of 5 milligrams per cubic meter are infrequent and short-term. During the period of time from late fall through spring, *Dinobryon* and *Peridinium* were dominant, while the remaining time period was dominated by *Chlamydomonas*, *Chlorella* or *Schizothrix*.

Total cell counts from periphyton samples ranged from 12 to 1370 cells per square millimeter throughout the drainage system. The outfall canal had a generally higher standing crop than Pond A. As expected, this variation is opposite to the phytoplankton distribution. *Dinobryon*, *Cosmarium*, *Euastrum* and pennate diatoms were found in most samples. The Chlorophyll-a concentrations varied between extremes of 0.25 and 19.15 milligrams per square meter. These values had trends similar to those of cell counts.

Data from these algal communities indicated the relatively unproductive nature of the landfill drainage system as dictated by the chemical conditions discussed previously. Alterations in water chemistry by leachate contamination will significantly alter these communities in both size and composition.

The established macroinvertebrate communities of the landfill drainage system ranged in size from about 50 to 3,800 organisms per square meter. These total counts reflect extremes, while most often, enumeration of organisms on the artificial substrate samples revealed between 300 and 800 organisms per square meter. The composition within these total counts revealed communities of high species diversity and a substantial percentage of species intolerant of organic pollution.

The Pond A community differed from the canal stations due to physical controls. The pond is standing water and therefore accommodates organisms not requiring flowing water. However, at Station 1 the canal is shallow and fairly narrow producing the water velocities required by or acceptable to some organisms. Total counts were generally higher in Pond A than in the outfall canal. The Biotic Index values averaged about 5 for Pond A and 11 for Station 1

Studies of bacterial and fungal populations in surface waters of the drainage system have not revealed any sustained changes from native conditions. Only slight fluctuations in these microbial measurements were recorded from the beginning of analyses to November 1972 (Volume II, Table 16). In the winter months of 1972 and 1973, Pond A and its effluent experienced a notable rise in microbial populations. However, this event was followed by a rapid decrease to normal levels of microorganisms. Fecal coliform counts in surface waters were consistently low, although in the summer months of 1972 and in the spring months of 1973 nonsustained elevations of fecal coliform counts were recorded. It is in these periods of the year when wildlife and cattle were observed around the drainage system. Surface runoff from the area surrounding the landfill site drained to the canal undoubtedly affected the quality of the water in the canal. Selective isolation of specific organisms (aerobic sulfur-oxidizing and gram (+) bacterial counts) have shown that these organisms tended to increase or decrease with the total count of the aerobic bacterial density. Accordingly, the anaerobic sulfur-reducing bacteria showed a similar comparison with total counts of anaerobic bacteria. While changes in bacterial density were detected, there is no indication of contaminated seepage from the landfill.

Ground Water Studies. The ground water monitoring program required the proper selection of well sites and the physical, chemical and microbial parameters to investigate. The efforts were centered on observing natural variations at the landfill site, establishing baseline criteria for water quality interpretation and the continuing monitoring of the ground water.

Sampling Locations. A total of 38 shallow wells were installed to monitor the effects of landfill on the ground water quality (Figure 32). These shallow wells, ranging from 10 to 30 feet deep, cover 40 percent of a 1,500 acre landfill. Considering the hardpan soil characteristics of this area and the desire to determine vertical as well as horizontal movement, 19 well installation areas were chosen with 12 areas having a cluster of two to three wells of varying depths and 7 areas of isolated 20-foot wells. The areas for well installation were selected after consulting natural drainage conditions, modified drainage characteristics and proposed filling schedules

From December 1970 through May 1971, six 20-foot wells (Wells 3, 5, 6, 10, 16, and 20) were available for monitoring in relatively close proximity to the first fill areas From May through October 1971, data was initially obtained from six additional 20-foot wells (Wells

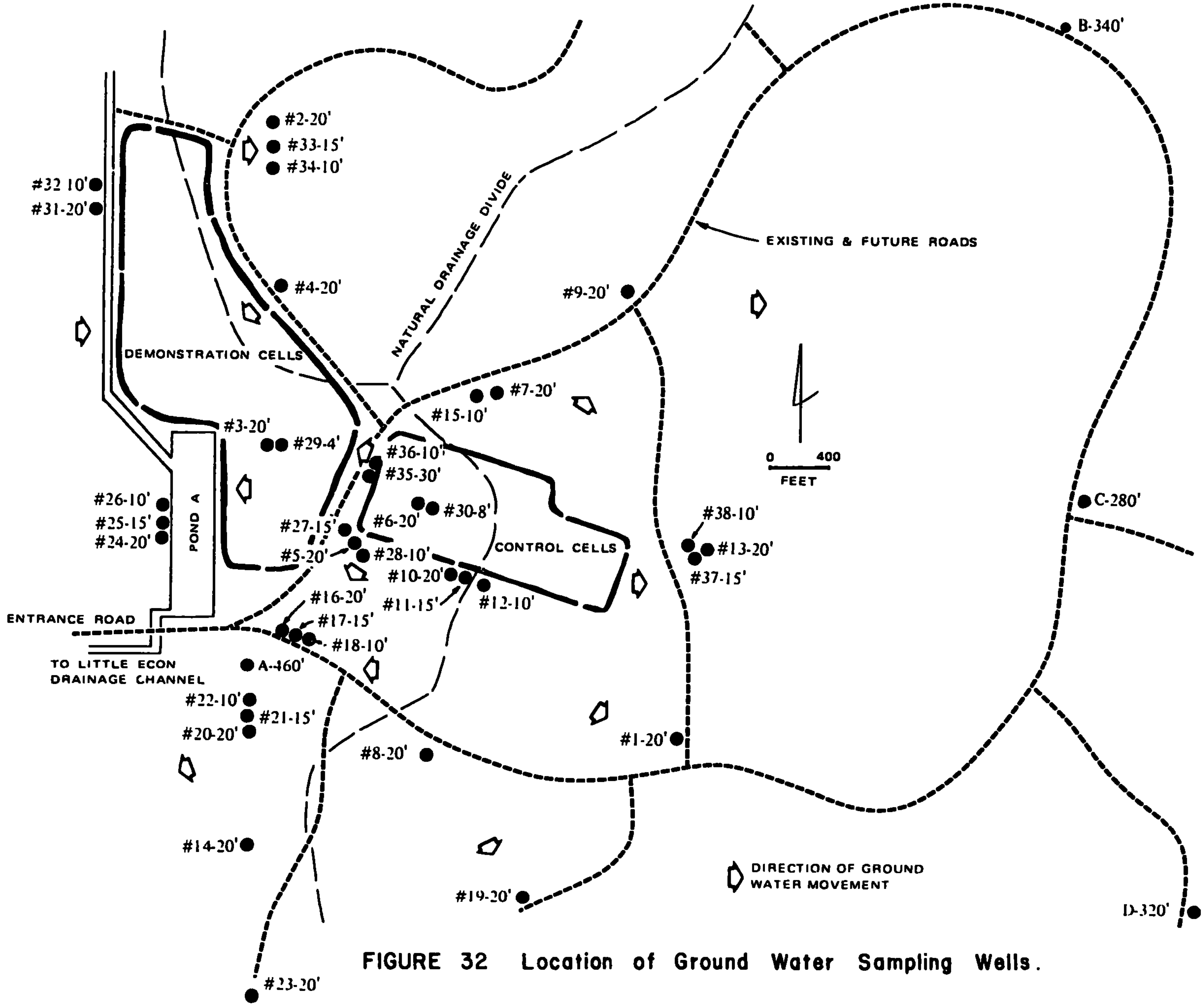

FIGURE 32 Location of Ground Water Sampling Wells.

4, 9, 13, 19, 23, and 24) located in more outlying areas. In October 1971 the addition of a 10 and a 15-foot well clustered around each original well brought the total to 21 shallow wells in the monitoring program (excluding Well 6 which was destroyed during landfilling operations in September 1971). Two additional wells were located in the fill to the bottom of a control cell and a demonstration cell. The control cell fill well (Well 30) was also destroyed in September 1971, shortly after installation. Additional shallow wells ranging from 10 to 30 feet deep, and two replacement wells installed in June brought the ground water monitoring program to the originally proposed 38 wells.

For the purpose of monitoring fluctuations in the ground water level, additional wells were driven near Wells 4, 5, 9, 10, 16, 19, 20, 23, 24, and 35. These wells were used only for water elevation determinations.

Deep well locations were selected after considering the flow pattern of the Floridan aquifer. Wells B, C, and D were installed along the eastern sector of the landfill property. Well A was installed in the western sector near the maintenance complex.

Well Design and Installation. Each test well was made of two-inch polyvinylchloride (PVC) plastic pipe. The 20 and 15-foot wells had a 10-foot well point section, and the 10-foot wells had a five-foot well point. The bottom was capped to insure that water entered the casing only through a series of screen slots 0.010 inches by one inch long (Figure 33). The top end of the casing was threaded to accommodate a PVC cap through which a piece of one-half-inch pipe was fitted and extended to the bottom of the well. Outside the cap was an elbow connection designed to accommodate the sampling apparatus (Figure 34).

Installation of the test wells was completed by professional well drillers. A four-inch steel casing was augered into the ground to the desired depth. The soil within the casing was then washed out and the two-inch PVC pipe and well point were placed in position. Coarse builders sand was used to backfill to a depth of ten feet. A two-foot concrete seal was installed Following this installation, native soil was used to fill from the concrete seal up to ground level. The four-inch steel casing was then withdrawn leaving the PVC pipe and well point in place Upon installation, approximately 2,000 gallons of water were pumped continuously from each well to remove any foreign material and to thoroughly flush the layer of filter sand.

Deep wells (Figure 32) extended to 460 feet (Well A), 340 feet (Well B), 280 feet (Well C), and 320 feet (Well D), and were cased to 239, 208, 163 and 168 feet deep, respectively. Well A presently serves as a potable water supply in addition to its monitoring function. Wells B, C, and D were four inches in diameter and Well A has a six-inch diameter.

Sampling Methods. Since ground water sampling required a high standard of validity, exact procedures and compatible equipment were used. Because one of the analyses was for trace metals, no metal could be a part of any well construction material or sampling equipment

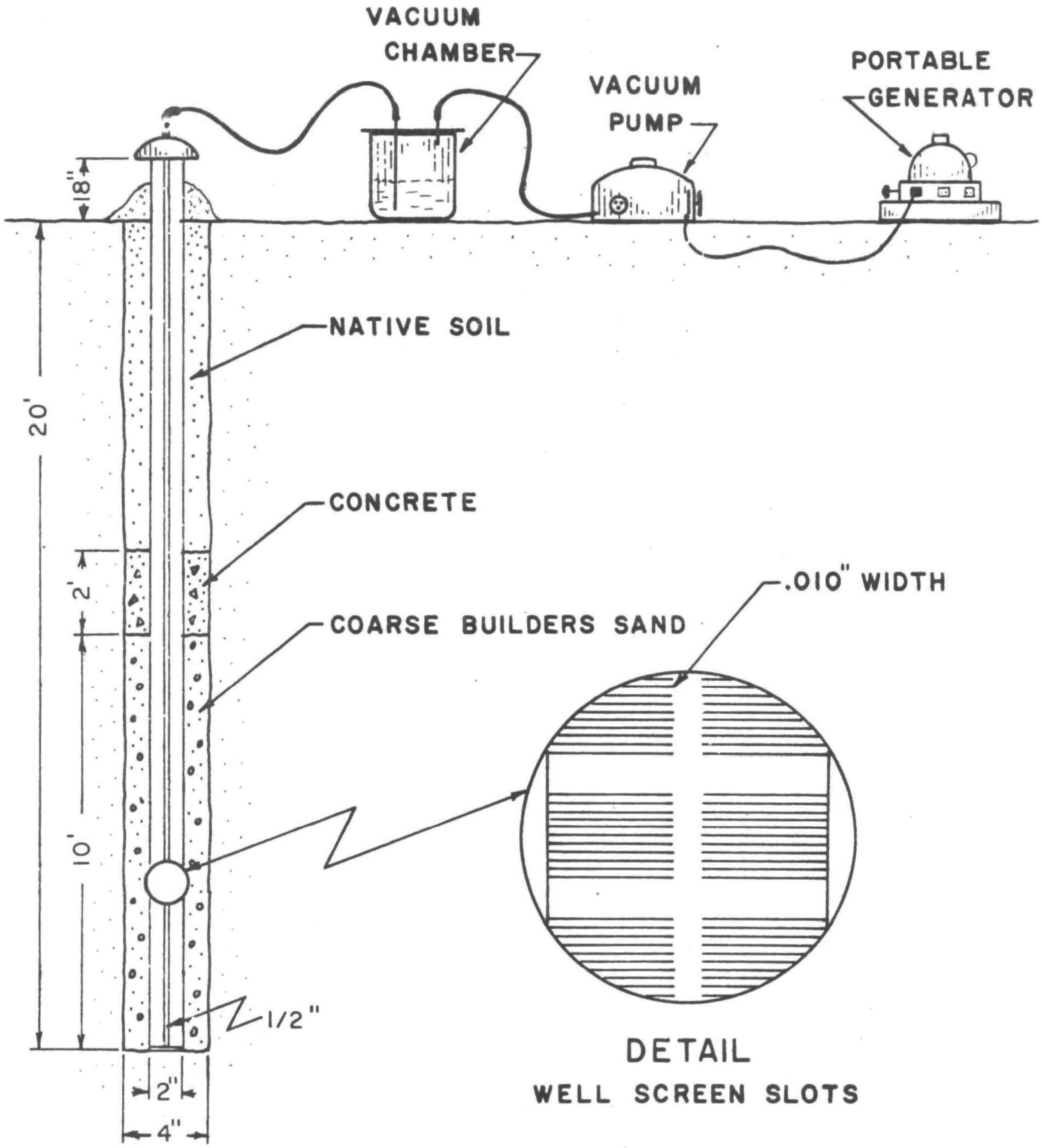

FIGURE 33. Profile Of Shallow Sampling Well.

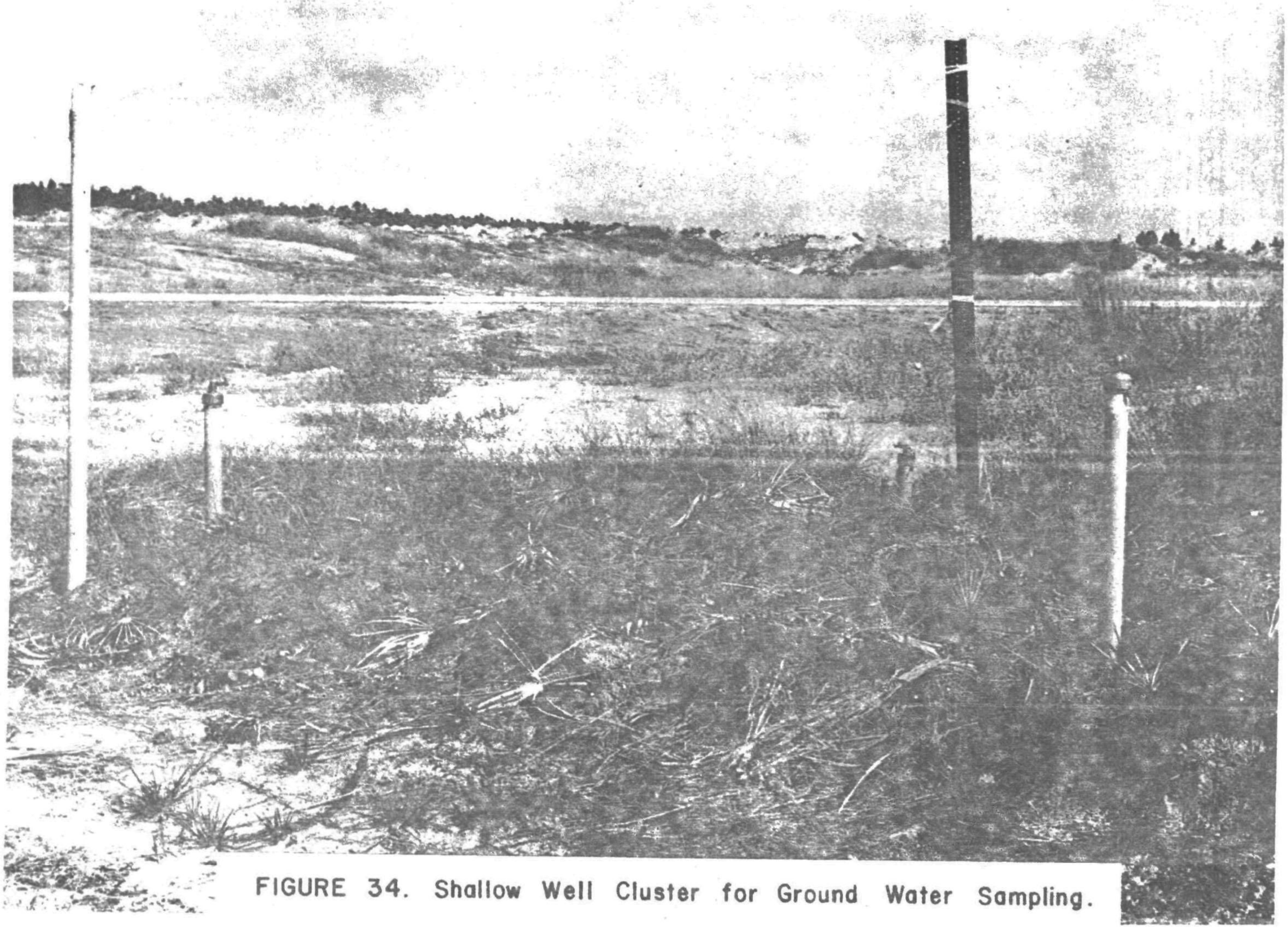

FIGURE 34. Shallow Well Cluster for Ground Water Sampling.

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In the process of obtaining samples from test wells, a vacuum chamber and connecting hoses, a vacuum pump, and a portable electric generator were used. The vacuum chamber, constructed of clear plastic tubing, was eight inches in diameter with a 1/8-inch wall It was 14 inches high with a three-gallon capacity. The bottom was permanently sealed and the removable top had a soft rubber gasket which allowed an airtight seal when attached to the vacuum pump. Water was drawn in with vacuum maintained through the use of two 3/8-inch diameter plastic tubes permanently inserted through the top. The chamber was attached to the well and the vacuum pump by two flexible rubber hoses which slipped over the ends of the 3/8-inch plastic tubes found on the chamber and attached to the well and vacuum pump with the threaded PVC connectors incorporated as part of each hose. A container could be placed in the chamber and a sample drawn directly into it, or the chamber could be filled and a sample poured into a container (Figure 35). A Bell and Gosset 1/4-horsepower high volume vacuum pump was used and was chosen for efficiency, light weight, and compactness. A McCulloch 1500 watt, 115 volt portable generator proved satisfactory as a power source for the vacuum pump. Again, light weight and compactness was taken into consideration in the selection of this power source.

The sampling process required the drawing and discarding of three vacuum chambers of water as a means of insuring fresh water in the well and to flush the hose leading to the chamber. All containers for chemical analyses samples were acid washed and rinsed repeatedly with distilled water before their use. Samples were placed in capped polyethylene bottles. These bottles were marked to insure repetitive use of the same bottle for the same well. Bottles were filled to overflowing, capped, and stored in a refrigerated box. The samples were then taken to the laboratory for analysis. Following use, all bottles were rinsed. The approximate volume of each well sample was about three liters.

For microbiological analyses, separate 250 milliliter and/or one liter samples were taken aseptically. Prior to sampling, amber glass bottles were autoclaved with aluminum foil covering the bottle mouths and secured with rubber bands. At sampling time, the foil covering the sterile sample bottle was punctured with the tube of the collecting apparatus and water was pumped immediately from the well directly into the sterile bottle. Sterile bottle caps were unwrapped and placed on the filled bottle. The collected water samples were then carried in refrigerated coolers to the laboratory where analyses began within a few hours.

Deep well sampling required the use of permanently affixed submersible pumps. Samples from Well A were obtained from an outlet prior to water treatment. Sample handling procedures were the same as those applied to shallow well sampling.

Sampling Schedule. Sampling frequency was modified as well installation progressed. Initially, each well was sampled monthly. Since that time and the completion of all well installations, the monitoring program was concentrated in or near the areas of past or active landfilling with the more remote wells being sampled only twice a year.

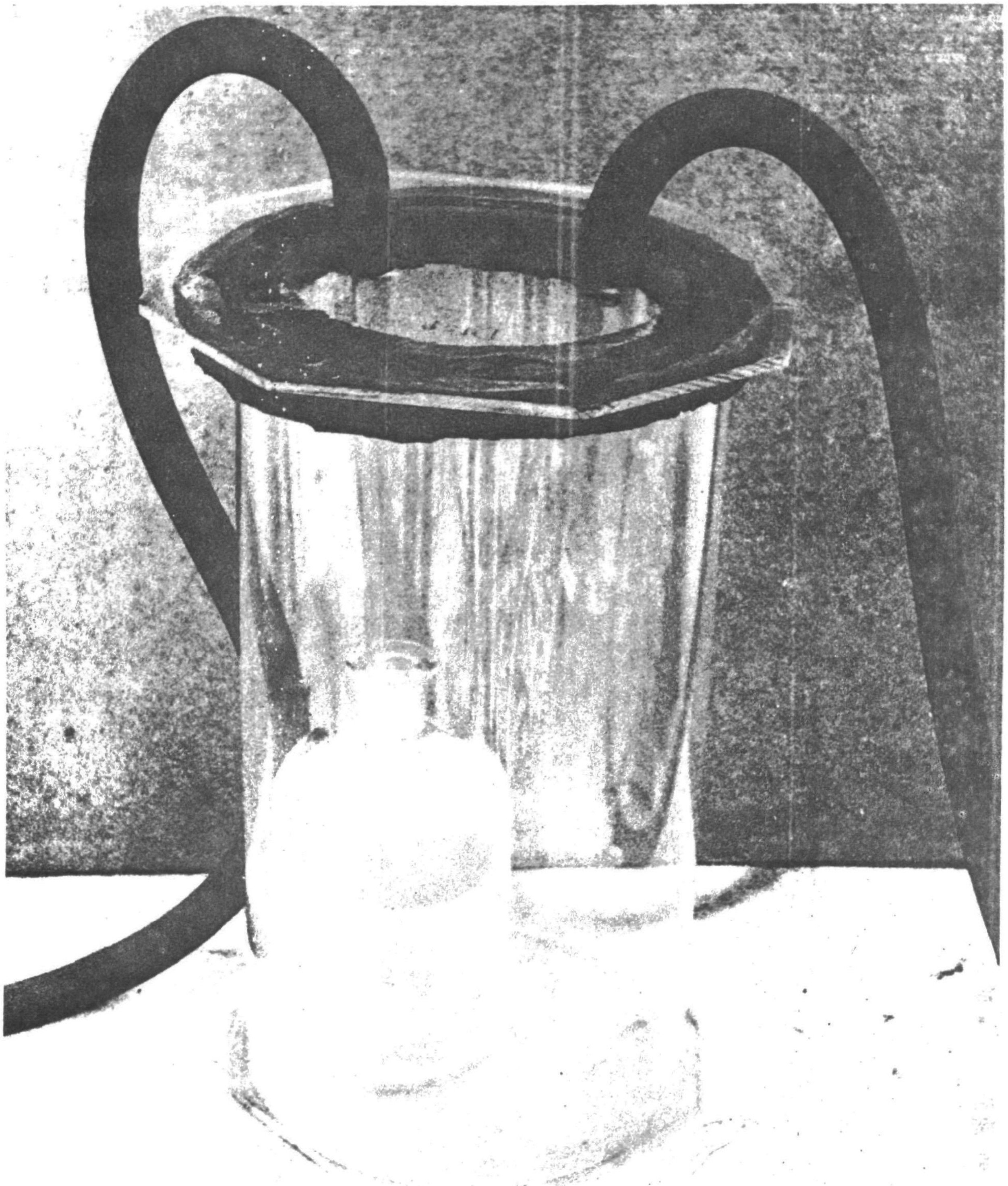


FIGURE 35. Vacuum Chamber for Shallow Well Sampling.

Physical, Chemical and Biological Analyses. The monitoring program for evaluating the ground water quality included pH (laboratory and field), chlorides, sulfate, chemical oxygen demand, phosphate (total and ortho), nitrogen (nitrate, nitrite, ammonia, and organic), temperature, conductivity, turbidity, solids (total, suspended and dissolved), calcium, magnesium, iron, aluminum, zinc, potassium, sodium, copper, and carbon analyses (Volume II, Tables 17 through 21).

Microbiological investigations included aerobic and anaerobic counts; sulfur reducing and sulfur oxidizing counts; *Staphylococcus* counts; bacterial survival studies; fungi counts; and fecal coliforms (Volume II, Table 22).

Physical and Chemical Properties of the Site. The results of three years of monitoring indicate the ground water at six of the shallow well locations has been affected by landfilling. Each of these six wells were either located within or immediately adjacent to filled cells. The wells displaying contamination were Wells 3, 6, 29, 5, 27 and 36. As shown in Figure 32, Wells 3 and 6 were penetrating through a demonstration cell and control cell, respectively, and Wells 5, 27 and 36 were adjacent to control cells. Although the latter three wells are also near the demonstration cells, best estimates of any ground water movement would place them downstream from the control cells. This hypothesis cannot be confirmed at this time. Wells 29 and 30 were located directly into the fill of a demonstration cell and control cell, respectively. Due to landfilling operations, these two wells were unavoidably disturbed, causing Well 30 to be completely unusable and Well 29 of questionable quality. It was not until January 1973 that samples could be obtained from Well 29. These samples required the use of a shallow well pump and were obtained with great difficulty. Although no data is available on the water quality in Well 30, it can be assumed that the well contained highly contaminated water.

The temperature of the ground water had a narrow range between 20 and 24C, with an overall average of 22C. For a given day and equal well depth, each well water sample was of a constant temperature. A comparison of ambient and ground water temperatures showed a one to three-month lag in the ground water temperature change corresponding to gross air temperature changes. An elevated temperature in contaminated wells was an exception and not a rule. Well 3 did attain a temperature increase of 4C above normal during the peak contamination in August 1972. This increase was of short duration and temperatures remained consistent throughout the remainder of the project. Extensive bacterial action and rainfall in late summer 1973 may cause another temperature increase.

Ortho-phosphates were below 0.04 milligrams per liter as phosphorus, with total phosphate generally ranging between 0.01 and 0.35 milligrams per liter. Landfilling did not cause a change in the phosphate concentrations.

Nitrogen determinations included four forms. nitrate, nitrite, ammonia and organic nitrogen. Nitrate and nitrite nitrogen concentrations were generally below 0.09 and 0.009 milligrams per liter, respectively. Contamination of ground waters did not produce an increased concentration in either of these oxidized forms. However, the ammonia and organic nitrogen determinations did show the influence of landfilling. Under natural conditions ammonia and organic nitrogen were generally less than 0.3 and 1.0 milligrams per liter, respectively. Contaminated waters had peak ammonia values of 13 (Well 29) and 26 (Well 3) milligrams per liter. Other contaminated wells had ammonia values less than 6 milligrams per liter; or as with Well 27, did not display an increase in any forms of nitrogen. In contaminated wells, peak organic nitrogen values were between 1 milligram per liter and 55 milligrams per liter. This latter value occurred in Well 3 at the time of maximum contamination. At the time of this excessive organic nitrogen content, ammonia nitrogen was relatively absent.

Averaged total iron concentrations of each well had a range of 0.15 to about 1 milligram per liter. In Well 3 iron content increased to 6.8 milligrams per liter in April 1972, and declined to 2.8 milligrams per liter in May 1973. An increase of iron in Well 36 elevated the concentration to 8.1 milligrams per liter in January 1973 followed by a sudden decrease to 2.9 milligrams per liter in July. The maximum iron contamination level in Wells 6, 5 and 27 was less than 3 milligrams per liter.

Aluminum concentrations were within the same range as iron. The highest concentration found was in Well 3 (13 milligrams per liter) in June 1971. In May 1973, the concentration had decreased to a level equal to those found before leachate generation. Wells 5 and 36 had maximums of 7.2 and 11.2 milligrams per liter, respectively. The latter decreased to 5.7 milligrams per liter by May 1973. As with iron, aluminum contamination was detected immediately in Well 3, but did not increase as rapidly as in other contaminated wells. The aluminum concentrations in Wells 6 and 27 remained below 1 milligram per liter.

The presence of zinc in ground waters was limited and usually below 0.1 milligram per liter. This applied to both contaminated and clean waters. In general, the concentration of this metal was varied in all wells. Copper seldom exceeded 0.01 milligrams per liter. As with zinc, this applied to contaminated and clean well waters. The near absence of copper was understandable due to its general absence from solid waste and its resistance to corrosion.

The major alkalies, sodium and potassium, were present in concentrations closely related to the corresponding ion, chloride. Sodium concentrations were typically less than 8 milligrams per liter throughout the site with many wells having half that concentration. Potassium was present in quantities of less than 0.3 milligrams per liter. Wells that had relatively high sodium concentrations did not have high potassium values. In Well 3, both alkalies immediately increased in concentration, sodium attained a maximum concentration of 128 milligrams per liter and potassium increased to 62 milligrams per liter. Both maximums occurred in August 1972. Since that time each decreased about 20 milligrams per liter. In contaminated water from Well 29, potassium concentrations always exceeded those of sodium. In contaminated wells adjacent to control cells (Wells 5, 27 and 36) this reversal from natural order by concentration did not exist. As an example, 128 milligrams per liter of sodium was present in Well 5 in May 1973; potassium, in the same month, had only attained a concentration of 0.6 milligrams per liter.

The alkaline earths investigated in this monitoring program were calcium and magnesium. In wells having a total hardness of less than 10 milligrams per liter, magnesium was the most abundant of the two. Wells having a total hardness of over 10 milligrams per liter had calcium as the primary alkaline earth. It was also noted that wells having a total hardness of more than 30 milligrams per liter were the only wells containing more calcium than sodium. Magnesium concentrations were most consistent throughout the site (averaged between 0.7 and 1.3 milligrams per liter), whereas calcium varied considerably (averaged between 0.3 and 12 milligrams per liter). Calcium concentrations increased to 160 and 85 milligrams per liter in Wells 3 and 36, respectively. Other contaminated wells did not reveal this increase and values remained at their natural level through May 1973. The concentrations of magnesium in Wells 3 and 36 increased to maximums of 13.6 and 20.8 milligrams per liter, respectively. The magnesium content in Well 36 exceeded that of calcium. An increase in magnesium, but not calcium, was found in Wells 5 and 27.

As indicated previously, average total hardness for each well revealed a wide range of conditions throughout the site (5.6 to 80 milligrams per liter as calcium carbonate). However, most wells had concentrations below 20 milligrams per liter. The higher concentrations were found in areas also containing high organic carbon content. Inversely, the areas with very little organic carbon had low hardness values. This relationship is of interest here. Many areas within the site are swamps of high humic content. This organic material is of high electronegativity and tends to retain the hardness causing elements. Clays also display this characteristic. Both free and retained hardness causing agents were measured in total hardness determinations. Precipitation as metallic sulfides discussed elsewhere can also be of importance. Total hardness in Well 3 was approximately 250 milligrams per liter since contamination was detected. Well 36 had a comparable increase, while other contaminated wells were below 100 milligrams per liter of hardness.

Solids analyses performed on samples from the shallow wells included total, suspended, and dissolved solids (Volume II, Table 17). In early samples some minor particulates were observed in the well waters; however, they were not observed after the wells were developed by successive pumping. Total solids were generally below 100 milligrams per liter with higher values occurring during the first few samples obtained for each well. The suspended solids and generally corresponding turbidity were below 50 milligrams per liter and 30 milligrams per liter, respectively. Both of these parameters decreased with successive samples from each well. After contamination, total solids increased without a subsequent increase in the suspended fraction. Therefore, total solids values typically represented an estimation of the total dissolved solids. Concentrations of total dissolved solids in Wells 3 and 36 reached peak values of approximately 1000 milligrams per liter. Dissolved solids did not reach this level of concentration in other contaminated wells. Specific conductivity, an indirect indication of mineralization, had corresponding trends and similar numerical values.

Chloride concentrations were variable but generally between 7 and 16 milligrams per liter under natural conditions. When leachate was generated from filled cells, chloride values rose to 260 milligrams per liter in Well 3 and decreased to 13 milligrams per liter in March 1973 (Figure 36). Well 29, which is adjacent to Well 3 and located in the fill, had chloride concentrations

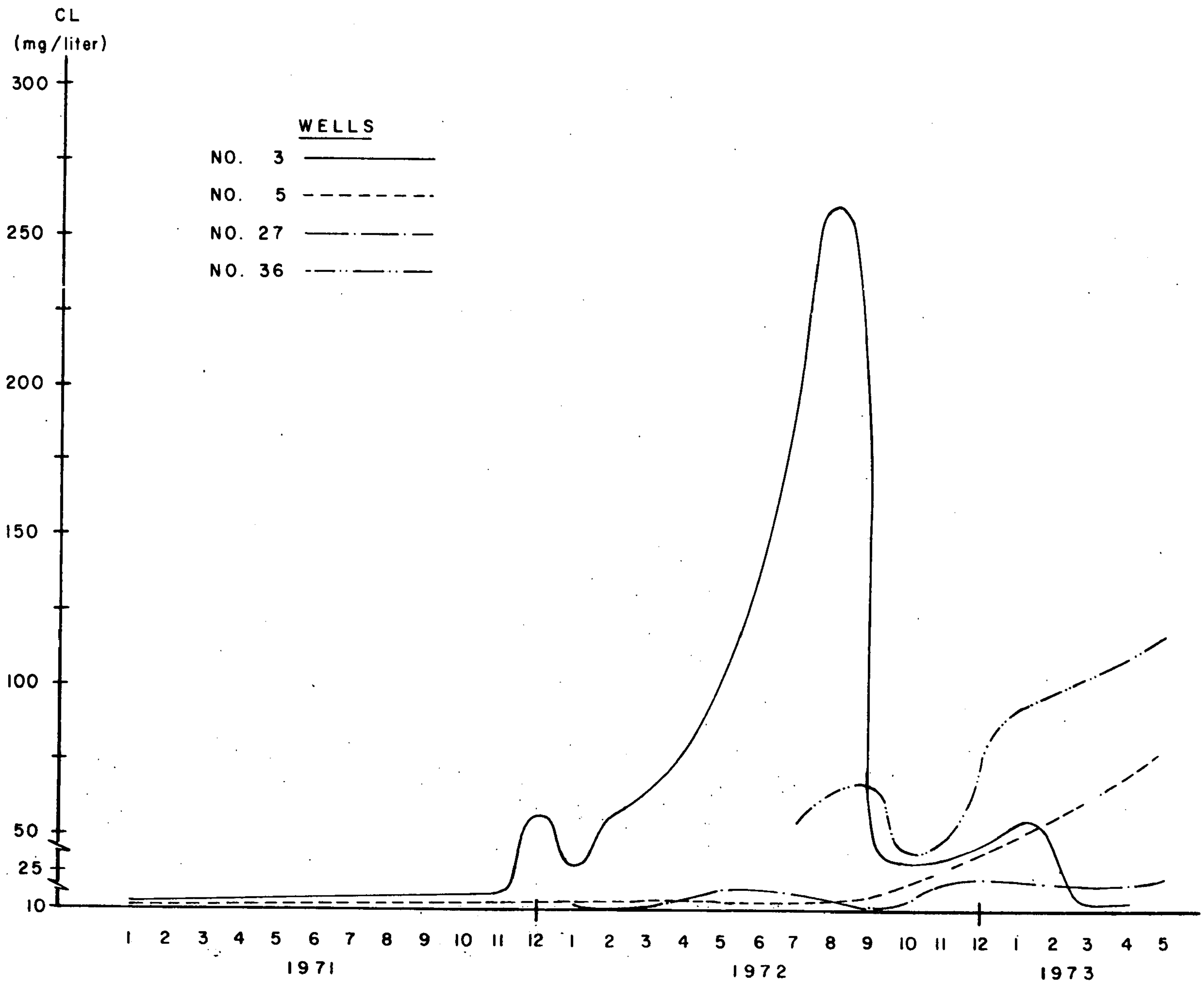


FIGURE 36. Changes in Chloride Concentrations For Selected Wells

around 20 milligrams per liter. Since Well 29 could not be sampled prior to January 1973, it is assumed that most of the chlorides were immediately carried out of the well environs. Wells 5 and 36, located near the control cells attained maximum chloride values of 80 and 120 milligrams per liter, respectively, in May 1973. As experienced with Well 3, chlorides indicated contamination but moved rapidly through the system leaving ground waters in the immediate area with normal chloride concentrations.

For the most part, the wells contained small amounts of sulfides over the period of study (0 to 5 milligrams per liter). A few exceptions did occur. Well 36 contained very high sulfide levels (100 to 200 milligrams per liter). Interestingly, Well 35, adjacent to Well 36 but 20 feet deeper (30 feet as opposed to 10 feet), showed no pollution as measured by organic carbon content and less than 1 milligram per liter sulfide. These data would tend to indicate that the elevated sulfide levels were due to biological activity in the waste.

The three well cluster of Wells 5, 27, and 28 perhaps provided the best data concerning sulfide production. All three of these wells had very low sulfide levels as of June 1972, but by November 1972, the sulfide level in the deepest member of the three (Well 5 at 20 feet) was over 300 milligrams per liter sulfide, and the intermediate depth well (Well 27 at 15 feet) contained 14.3 milligrams per liter sulfide. Organic carbon analyses for these three wells showed similar changes, so there can be no doubt that the observed increases were related in some way to the increased organic carbon content of these wells.

Well 6, located within the control cells, contained only 0.4 milligrams per liter of sulfide sulfur as of March 1973, but had risen to 27.8 milligrams per liter by July 1973. A concurrent increase in acidity, carbon and inorganic content was observed. This pattern is the same as that for other polluted wells which have been previously observed with the exception of Well 3.

Well 3 presented an entirely different picture. Although contamination began in November 1971 and continually increased through August 1972, analyses did not show concurrent increases in sulfide. If the increase in sulfides found in Wells 5, 27 and 36 were due to increased organic carbon content, then Well 3 should have shown a similar increase. All polluted wells show a similar drop in pH, so this factor is ruled out as a causal agent of the observed increase in sulfides. Since Well 3 draws water from directly underneath a waste cell while the other wells, although close by, are outside the waste cells, it is possible that the organisms responsible for sulfide production cannot survive under conditions of extreme pollution such as exists in Well 3; whereas they thrive along the concentration gradient of an advancing mass of polluted ground water. Also, it is most likely that a certain amount of chemical fractionation has occurred as the polluted water moved through the soil, and certain inhibitory components may have been removed as the leachate migrated laterally through the soil. It is possible that in time, as pollution increases, the sulfide levels in Wells 5, 27 and 36 may start to decline as conditions become unfavorable for the microorganisms involved in these transformations. There is probably a rapid, massive, downward movement of pollutants into wells immediately underneath waste cells and a more subtle, much less rapid lateral movement of leachate out of the cells into surrounding ground waters. Well 29, drilled directly into the cell overlying Well 3, contained only 2.3 milligrams per liter sulfide in March 1973. It is possible that all of the very degradable organic matter in the cell (which was about 1 year old at that time) had decomposed by March 1973.

One might expect that large amounts of sulfide would be precipitated as metallic salts, in view of the high concentrations of elements such as iron and zinc found in polluted well waters. These metallic sulfides, once formed, should precipitate out and be filtered out as the ground water flows through the soil. It is possible that the presence of large amounts of sulfide could decrease the metal content of the leachate significantly. It is also possible that the sulfides present in the polluted waters represent preexisting bound sulfides which have been somehow solubilized by the chemical nature of the leachate as it moves through the soil. Further investigation of the presence or absence of sulfide producing organisms in these waters is needed before any more definite statement can be made. It might also be borne in mind that the absence of sulfide producing bacteria could indicate that the sulfides were produced at some point distant from the well site at which they were collected.

The sampling techniques used in this study were subject to criticism, particularly with respect to sulfide determinations. Samples were aspirated out of the wells under vacuum and then were transported to the laboratory over some distance. Investigators were aware of these difficulties but felt that for comparative purposes the method would suffice. In order to check the procedure out further, Well 3 was sampled August 8, 1972 by aspirating a 1/2-liter sample directly into a bottle containing a zinc acetate solution. The resulting zinc sulfide precipitate was concentrated and sulfide content determined. This analysis showed Well 3 to contain 6 milligrams per liter sulfide, while the routine procedure gave a value of 2 milligrams per liter. Although a loss of 4 milligrams per liter did occur in this one case, it is still felt that for comparative purposes, the original method worked quite well for repetitive analyses.

Chemical oxygen demand ranged from approximately 0 to 110 milligrams per liter throughout the site. Very few wells had an average concentration greater than 30 milligrams per liter. Wells displaying a naturally high content of chemical oxygen demand were located near swamp land. In Well 3, the concentration steadily increased to 6,000 milligrams per liter by August 1972 (Figure 37). This peak occurred 10 months after the overlying cell was completed and was followed by a rapid decrease to a concentration of 700 milligrams per liter in May 1973. An increased chemical oxygen demand was initially detected in Well 5 during June 1972. This increase was not substantial until November 1972, when a concentration of 210 milligrams per liter was attained. Since that time the chemical oxygen demand has increased to 815 milligrams per liter. In Well 27, the concentration has increased to only 66 milligrams per liter. In samples from Well 36, the chemical oxygen demand increased to 1,700 milligrams per liter in September 1972, decreased in October, gradually increased to 2,950 milligrams per liter in March 1973, and then decreased in May.

Data obtained from carbon analyses of the shallow wells of the solid waste disposal site are presented in Volume II, Table 21. These data show that only six of the 38 shallow

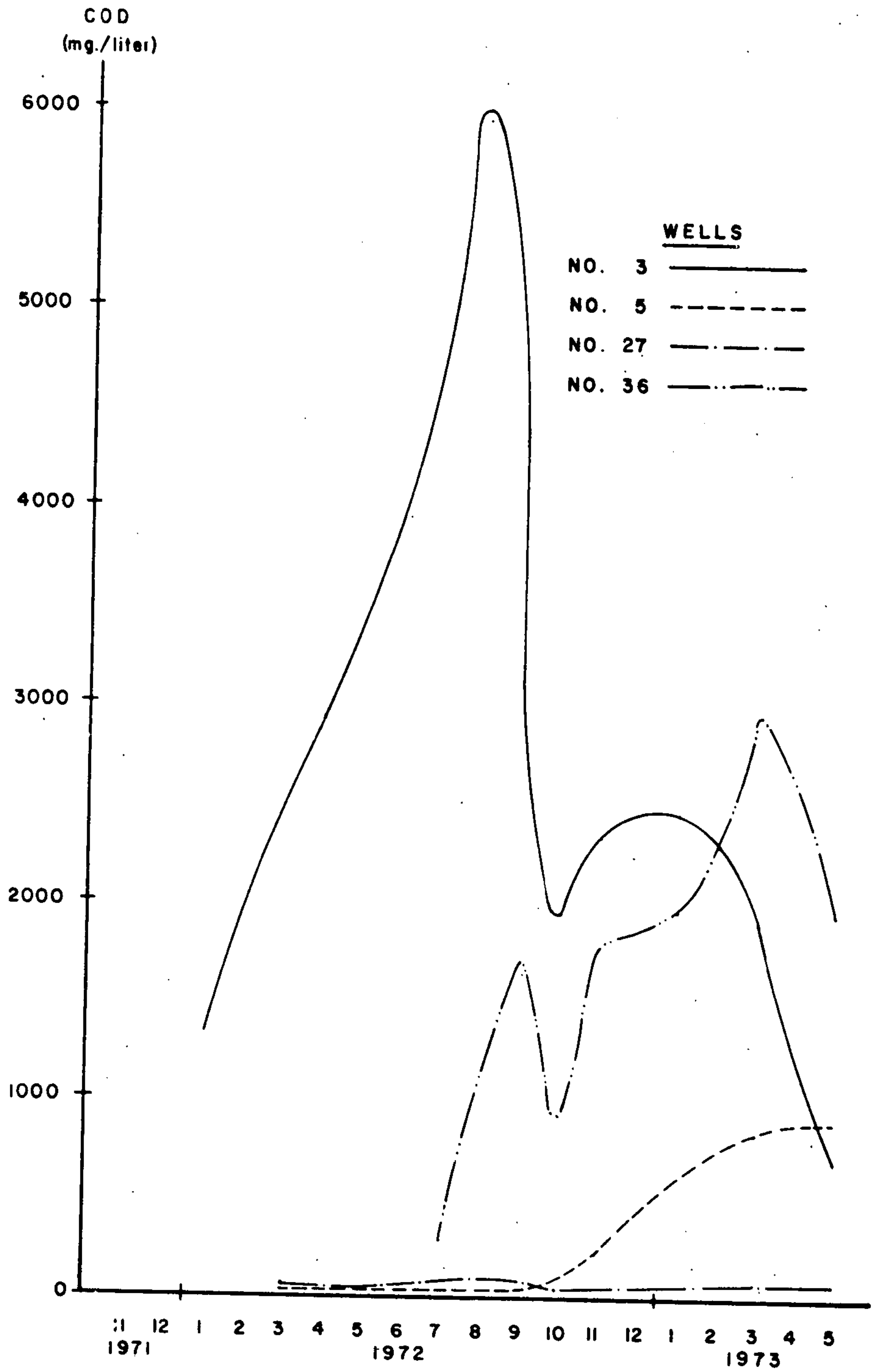


FIGURE 37. Change in Chemical Oxygen Demand for Selected Wells

wells drilled at the site have been polluted by chemical leachates. All six of these wells were either located within (3, 6, 29) or immediately adjacent to (5, 27, 36) waste cells which indicates that there has been practically no movement of the leachate through the ground water during the course of this study.

Typically, the quality of ground water in the unpolluted wells varied considerably according to the location of the well and the type of substratum which drained into the well point. Hardly ever does the organic carbon content of these well waters exceed 50 milligrams per liter. The organic carbon present in these waters is composed almost entirely of various humic and/or fulvic acid fractions of lignified vegetable matter present in peat deposits or bogs as previously discussed. These materials impart a yellow-brown color and a certain degree of acidity depending upon their concentration.

Two cluster well groupings, Wells 10, 11, 12, and 2, 33, 34, provided excellent examples of the range of water quality normally encountered in the area.

The Wells 10, 11 and 12 cluster, although immediately next to a waste cell (Control Cell 8), consistently produced water of good quality. These waters were consistently devoid of any coloration, had very low total dissolved solids, and usually exhibited organic carbon contents on the order of 5 to 50 milligrams per liter; on several occasions, only traces of organic carbon could be detected. These wells were situated almost exactly on top of a drainage divide. It is assumed that the waters which entered at their well points did so through beds of fairly pure sand; hence the lack of dissolved organic matter.

The Wells 2, 33 and 34 cluster, however, consistently exhibited a dark yellow-brown coloration, higher total dissolved solids values, higher organic carbon content (up to 50 milligrams per liter) and lower pH (down to 4.0) than did the previous cluster. All of these characteristics can be attributed to the presence of humic substances. These organic materials were for the most part nondialyzable (tend to indicate molecular weights of over 5000 or some aggregate thereof) and contributed to the observed acidity of these waters. Aeration of waters from Wells 10, 11, and 12 caused a rise in pH from about 4.9 to 6.7, whereas the pH of water from Wells 2, 33 and 34 stayed at or near 4.0 to 4.2. The latter cluster was located to one side of a drainage divide on the edge of a gradual slope adjacent to a bog. It would appear as though the well points of these three wells received water from or are located in a layer of peat or similar organic deposit.

From a study of the data, it can be concluded that any well water from the site of the study which contained greater than 50 milligrams per liter organic carbon and exhibited a pH of less than 4.5 after aeration was polluted.

The organic carbon content of Well 3 was initially about 15 to 25 milligrams per liter, but in December 1971 it had risen to 48.7 milligrams per liter. Following this initial slight rise, the carbon content slowly increased to 353.3 milligrams per liter by February 1972. The organic carbon content further increased to a peak of 6,669 milligrams per liter by June 1972. A value of 792 milligrams per liter was recorded in January 1972. Well 29, a companion of Well 3, contained 59.0 milligrams per liter organic carbon in March 1973.

Prior to May 1972, a cluster of Wells 5, 27, and 28, located just outside Control Cell 1, had shown no pollution and had fluctuated between 2 to 19 milligrams per liter organic carbon. Since that time, the carbon content has steadily increased in Wells 5 and 27 to 366 and 59 milligrams per liter, respectively. The carbon content of Well 28 (the shallowest member of the series) did not change appreciably, indicating no pollution at the 10-foot level. These data tend to indicate that leachate moved laterally out of Control Cell 1 below a 10-foot depth and is continuing to move laterally. This conclusion is further verified by the carbon analyses from Wells 35 and 36 (30 and 10 feet deep, respectively) which are immediately west of Control Cell 6. Well 36 was already polluted when first sampled, therefore the rate of pollution and lateral migration of the leachate is unknown.

Well 6, located within the control cells, showed an increase in organic carbon from the July 1973 sampling which is attributable to a downward movement of leachate within Control Cell 5. Only 14 milligrams per liter of organic carbon were found in this well in March 1973; whereas, 150 ppm were measured in July 1973. A concurrent increase in sulfide concentration and decrease in pH were noted. According to records maintained at the landfill site, a total of 13,278 tons of waste were dumped into Cell 5 over the period of October 1971 to January 1972.

In all tne polluted wells, the organic carbon content increased and the pH decreased. This is particularly evident when one compares the pH of a well before and after aeration. Well 5 illustrates this point. In November 1972 the pH of the well water rose from 5.13 to 5.79 upon aeration. In May 1973, the pH had dropped to 4.28 and rose only to 4.80 even after one hour aeration. If the acidity was due to highly volatile constituents, the pH value would have increased significantly after aeration. The organic carbon content of Well 5 rose from 52 to 366 milligrams per liter over this same 6 month time period. The observed failure of the pH to rise upon aeration is due to the presence of relatively large amounts of fatty acids which resulted from the anaerobic decomposition of the organic matter by the microbes present.

Qualitative thin-layer chromatographic analyses of Well 3 water showed a complex mixture of lipoidal materials to exist which is high in fatty acid content. Much of the odor detected in these polluted waters other than H_2S is due to these fatty acids.

Qualitative thin-layer chromatography failed to show any free amino acids in water from the polluted wells in concentrations in excess of 10 milligrams per liter. Sephadex column chromatography and dialysis experiments confirmed that practically all of the organic carbon present in the polluted well waters from the waste disposal site was in the form of low-molecular weight components, mostly fatty acids.

Biological Properties of the Site. Total counts of bacteria were employed to indicate the overall microbial response to nutrient enrichment of waters, as well as possible leaching of microorganisms into the water. Initial water samples taken from the shallow wells throughout the site tended to show higher bacterial counts than what was characteristic in succeeding months. This observation can be attributed to the period of stabilization pumping of the wells and establishing sampling techniques. In the ground waters not shown to be contaminated by leachate, the total counts of aerobic bacteria have ranged from 100 to 1,000 organisms per milliliter. Unsustained deviations may have resulted from sampling errors. These bacterial populations were a mixture of species typically found in soil and/or fresh water (Volume II, Table 22). Their identity will be discussed in connection with the effects of the landfill on ground water.

Following stabilization of wells, the total anaerobic counts ranged from 10 to 100 organisms per milliliter of ground water. Laboratory tests indicated that a high percentage of the anaerobic isolates were facultative rather than obligately anaerobic. The lower counts of anaerobes may indicate the lack of complete anaerobiosis in the well waters, or more likely, that sampling procedures were of the nature that fastidious anaerobes could not be properly protected from oxygen.

Fecal coliforms (as well as *Salmonella*) would serve to indicate leaching of microorganisms, as these organisms would not be normally present. Prior to the start of fill operations at the site, fecal coliforms and *Samonella* species in ground water were not detected.

Enumeration of sulfur-oxidizing bacteria was intended for possible correlation to any significant increases in sulfate content of the water. Sulfur-reducing bacteria would be quantitated to show anaerobic decomposition of sulfur-containing organic nutrients. The sulfur-utilizing bacteria could be established as part of the normal flora and any major changes in their total population would give an indication of some influence by the presence of decomposing solid waste. Sulfur-oxidizing bacteria and sulfur-reducing bacteria were consistently a small percentage of the bacterial composition of the native ground waters.

Filamentous fungal counts were taken to give possible indication of changes in water quality, e.g., the establishment of anaerobiosis. Counts of filamentous fungi in natural ground waters were consistently low (less than 100 per milliliter). Gram positive bacterial counts were also made to show any changes in water quality coincident to movement of leachates. Only a small percentage of the bacterial composition of natural ground water was gram positive.

Microbiological analyses have indicated that of the 38 shallow wells providing water samples, only those installed directly within a demonstration cell (Wells 3 and 29), a control cell (Wells 6 and 30), and two clusters immediately adjacent to the control cells (Wells 36, 5, and 27) have yielded water containing leachates. Water at the Well 3 site became contaminated soon after filling at the site began. Total counts of aerobic and anaerobic bacteria increased to highest values in the winter months of 1971-72, a 10- to 20-fold increase. A rather similar buildup of aerobic and anaerobic bacterial population developed again in the winter months of 1972-73.

In both instances the numbers of organisms declined to background levels during the summer months of 1972 and spring 1973. It was interesting to find that when bacterial densities declined in the summer of 1972, only one species of bacteria was detected in Well 3 water and one species of yeast. Coincident with changes in bacterial density was a lowering of the pH to 4.3 in the water. The pH increased slightly at the time the bacterial density rose in the 1972-73 winter months and heterogenous species were again represented. The lack of rainfall to induce extensive leachate movement and the slightly higher pH of winter are a contrast to the summer conditions. These contrasting bacterial environments influenced the bacterial community.

The yeast isolated from Well 3 water was not identified. The facultative aerobe which was the sole dominant species of bacteria found in the summer of 1972 was identified as a species of *Achromobacter*. In a special study it was determined that this organism developed optimally only if the growth medium was supplemented (e.g., 25% v/v) with water obtained from Well 3. Moreover, it was established that the isolate grew optimally over a wide pH range, from pH 3.5 to pH 6.0 under aerobic conditions.

Neither fecal coliforms nor *Salmonella* were detected in water samples pumped from Well 3. The high acidity in the ground water beneath the demonstration cell undoubtedly contributed to the inability of these organisms to survive in the water. As shown in Volume II, Table 23, when cultures of *Salmonella* and *Escherichia coli* were suspended in the acidic water (pH 4.3 - 4.5) obtained from Well 3, 99 percent of the initial cell population was inactivated in 48 hours. By the tenth day, the organisms could not be recovered. Similar results were observed when *Staphylococcus aureus* was suspended in this water. *Pseudomonas aeruginosa* was much more sensitive. This species could not be recovered after 3 days. In contrast, when each of the 4 organisms was suspended in water from Well 3 in which the pH was neutralized with base, survival was considerably longer (Volume II, Table 24). *Escherichia*, *Salmonella*, and *Pseudomonas* could be recovered as long as 10 weeks and could have been detected much longer. *Staphylococcus* appeared to be less durable and failed to survive for more than 1 to 2 months. These data suggest that the high acidity developed during anaerobic decomposition contributed to elimination of pathogens usually associated with water, as well as other organisms.

Bacterial counts in cluster Wells 5, 27, and 36 have indicated leachate movement from the control cells. Well 36 was first analyzed in December 1972 and found to have a high total bacterial count similar to Well 3. The bacterial count was 25,000 per milliliter in Well 36. Two subsequent analyses (March and May 1973) showed that the counts decreased to less than 500 aerobic organisms per milliliter, again in agreement with events in Well 3. In Well 36 water, the total anaerobic count was greater than the aerobic count in May 1973. Neither fecal coliforms nor *Salmonella* were detected. All other analyses yielded negligible results. Bacterial counts from Wells 5 and 27 revealed higher populations in the 15-foot depth (Well 27).

When water could be drawn from Well 29 there was a high bacterial population, particularly anaerobic bacteria. This was true of both the total anaerobic count and the *Desulfovibrio* count Other microbiological parameters show elevated values but the outcome of anaerobic analyses was notable. It should be noted that Well 29 extends to the bottom of a demonstration cell (4 feet) and water could not be withdrawn through normal sampling procedures

Water samples obtained from Wells 24, 25, and 26 (located adjacent to Pond A) have not indicated any leachate contamination, although the water samples have shown higher bacterial counts than that usually observed as background. Increased bacterial densities were noted in the latter part of 1972 and paralleled the elevation of bacterial populations in Pond A and its effluent. Organic carbon data again did not parallel the rise in bacterial counts in Wells 24, 25, and 26. This well cluster has displayed sporadic suspended solids concentrations and other typical characteristics of an unstabilized well as experienced during the initial sampling of all wells.

It might be considered that chemical analyses are a more reliable indicator of leachate movement than total bacterial counts. Bacterial counts fluctuate, and apparently, intensified chemical content tends to reduce the bacterial population. Examination of waters for higher bacterial populations could be misleading as conditions of chemical toxicity may play a role in reduction of bacterial numbers.

The microbiological data recorded for all other wells which are peripheral to the fill area have not indicated leachate movement away from the landfills. Total counts taken on samples of wells studied over a long period show a general reduction, particularly Wells 4, 9, 13, 16, 19, 20 and 23. This condition was expected due to the gradual reduction of suspended solids (available substrate) and the time involved in complete well stabilization.

Dominant species of aerobic bacteria found in both ground and surface waters have been of the genera *Pseudomonas, Achromobacter, Alcaligenes,* and *Flavobacterium* Similar observations were noted in studies on fresh water from a lake (Collins, 1963).[36] The non-fecal coliform, *Enterobacter,* was isolated often but this organism was present as a small percentage of the total population. *Thiobacillus* was isolated frequently. Of the gram positive bacteria isolated, species of *Bacillus* and *Arthrobacter* were the most prevalent. Occasionally isolates of saprophytic *Staphylococcus, Sarcina, Brevibacterium,* and *Corynebacterium* were identified. These bacteria represent a diversity in metabolic processes within the natural ground water.

The usual diversity in bacteria was noted in those wells which were shown to have become contaminated with solid waste leachate (Wells 3, 5, 6, 27, 29, and 36). However, a single type of organism, *Achromobacter,* increased in percentage of the total population in the summertime, when contamination was at its greatest level. The usual diversity in bacteria reappeared in the fall and winter months when a reduction in contamination was experienced. While the bacterial flora in Wells 3, 29, 6, and 36 is a mixture of several species of bacteria, it is apparent that a gram negative curved rod-shaped bacterium was becoming more prevalent in these waters. Stained preparations suggested one or more species of vibrio-type bacteria. Also, a corynebacteria type organism was more common.

The water sampled from Well 29 (four feet deep and within the fill material of Demonstration Cell 0) was enriched and again a mixed flora of aerobic bacteria was isolated. A predominant group of bacteria in this well was the genus *Bacillus*. It is possible that the shallowness of Well 29 (4-foot depth) and the fact that the water contained a heavy suspension of soil particles, may have been responsible for the presence of these spore forming *Bacilli* These organisms are prevailing in soils owing to the resistant property of its endospore. Throughout the study, a dense population of these spore forming bacteria could be correlated to intrusion of surface particles into ground water.

Various methods were used in an attempt to isolate fecal coliforms from ground water. Tests for the direct isolation of fecal coliforms proved negative in all instances. Analyses of isolates obtained by other methods of coliform detection showed that none was a fecal coliform. Tests for enterococci were negative for ground water samples. Accordingly, no species of *Salmonella* were isolated directly or by enrichment.

The 50 isolates derived from total aerobic bacterial counting plates were differentiated under aerobic conditions and the metabolism demonstrated by these organisms were primarily oxidative. It should be indicated that more than 80 percent of the isolates were found to be facultative with respect to oxygen requirements. These organisms may serve to keep the oxidation-reduction potential favorable to the anaerobic digestion of the waste (Hobson and Shaw, 1971).[37] The organisms may be associated with the initial hydrolysis of the waste under anaerobic conditions. The isolates failed to show aerobic degradation of starch or cellulose, although a large percentage of them did hydrolyze milk and gelatin protein and lipids in vitro. The same organisms were not tested for their abilities to metabolize complex molecules under an anaerobic atmosphere. Until just recently (June 1973), facilities to conduct large scale analyses of anaerobic activities of facultative, aerobic bacterial isolates, were not available. The accepted identification schemes for these organisms were keyed to aerobic metabolism, however.

The selection of gram positive bacteria in phenylethanol agar has indicated that these organisms constituted only a very low percentage of the bacteria present in ground waters. *Staphylococci* (coagulase positive) were never detected. This finding supports the data which showed that the bulk of the aerobic isolate in total count analysis were gram negative bacteria. As already indicated, these gram negative bacteria were mostly facultative and were capable of playing a role in anaerobic digestion.

A complete record of the obligate anaerobic bacteria was probably not accomplished owing to the extreme sensitivity of these organisms to oxygen and inability to provide highly reduced conditions throughout every step of the sampling process. An examination of isolates from total anaerobic count platings and cooked meat medium enrichments showed that 95 to 99 percent of these organisms were species of the endospore-forming *Clostridium* or facultative *Bacillus*. Clostridial isolates were examined for identification and their biochemical activities. Further biochemical studies will attempt to demonstrate quantitatively the numbers of anaerobes which are amylolytic, cellulotic, and proteolytic.

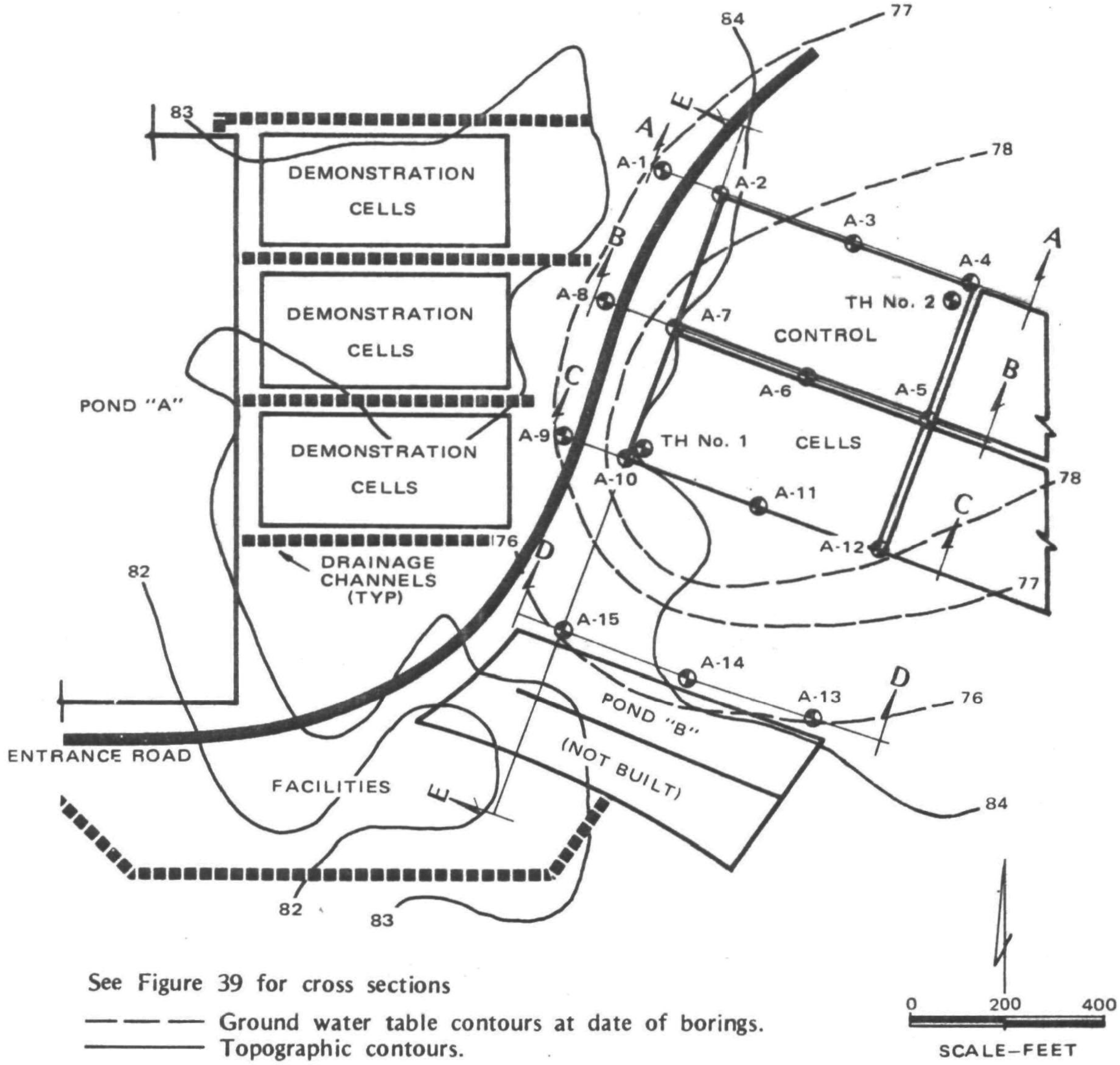
An anaerobic bacteria indicator can be applied to the landfill study. Quantitative enrichment techniques for sulfur-reducing bacteria showed that these organisms (principally *Desulfovibrio*) were present in high numbers in Well 29 water which was in closest contact with the anaerobic digestion taking place in Demonstration Cell 1. No other ground water sample showed more than a low background count of the sulfur-reducing bacteria. These organisms decompose sulfur-containing materials to release sulfide or reduce inorganic sulfur compounds. A high organic content is probably necessary to support the anaerobic sulfur-reducing organisms. The increases in numbers of the sulfur-reducing bacteria serve to indicate a high organic content in ground water. Counts of 1,000 to 3,000 sulfur-reducing bacteria per milliliter were observed in water from Well 29 whereas the counts were normally less than 100 (or zero) in all other ground water samples.

There is no indication that ground water is being contaminated beyond the periphery of the fill cells. The bacterial populations remained heterogeneous with some evidence that in the more polluted ground water, some species could become predominant in time. A larger bacterial population was observed as ground water received leachate but it declined as conditions became toxic.

Deep Well - Water Quality. The sampling of waters from the Floridan aquifer was extremely limited. Data reflected an alkaline condition with pH values between 7.2 and 7.5. Hardness determinations resulted in a wide range of conditions from 53 to 176 milligrams per liter as calcium carbonate. Likewise, conductivity and total dissolved solids displayed a range of 154 to 379 micromhos per centimeter and 105 to 264 milligrams per liter, respectively. Chemical oxygen demand of the water was low (8 to 17 milligrams per liter). Concurrent carbon analysis revealed low organic carbon concentrations (less than 20 milligrams per liter) and high carbonate carbon values. None of the wells contained more than 1 milligram per liter of sulfide. Values obtained for methylene blue active substance from these waters were about 30 micrograms per liter. Total aerobic and anaerobic counts of bacteria in artesian waters ranged from 1.5×10^3 to 30 organisms per milliliter. Fecal coliforms were not detected. No leachate contamination was detected.

Soils Studies

Citations from the Ardaman report[2] on geology and hydrology have been covered generally under the section on Site Selection. Details of soils studies from that report and by Florida Technological University are of interest. Ardaman took three lines of borings through the center and edges of the control cell site (Figure 38). Boring logs to 50 feet deep and sieve analyses indicated a top layer 14 to 30 inches thick of loose, permeable fine sand (K = 700 to 800 feet per month) with a more dense and more impermeable fine sand, "hardpan", below this layer (Figure 39). Inspection of the logs indicated the hardpan to be from two to six feet in thickness and to generally overlie the entire site. This reddish brown to dark brown fine sand was readily evident in the cuts for cell construction and on excavation produced some chunks or rocks which were soft and breakable when wet. Sieve analysis of the hardpan indicated it was about 90 percent (by weight) finer than a Number 60 U.S. Standard sieve size. Ardaman



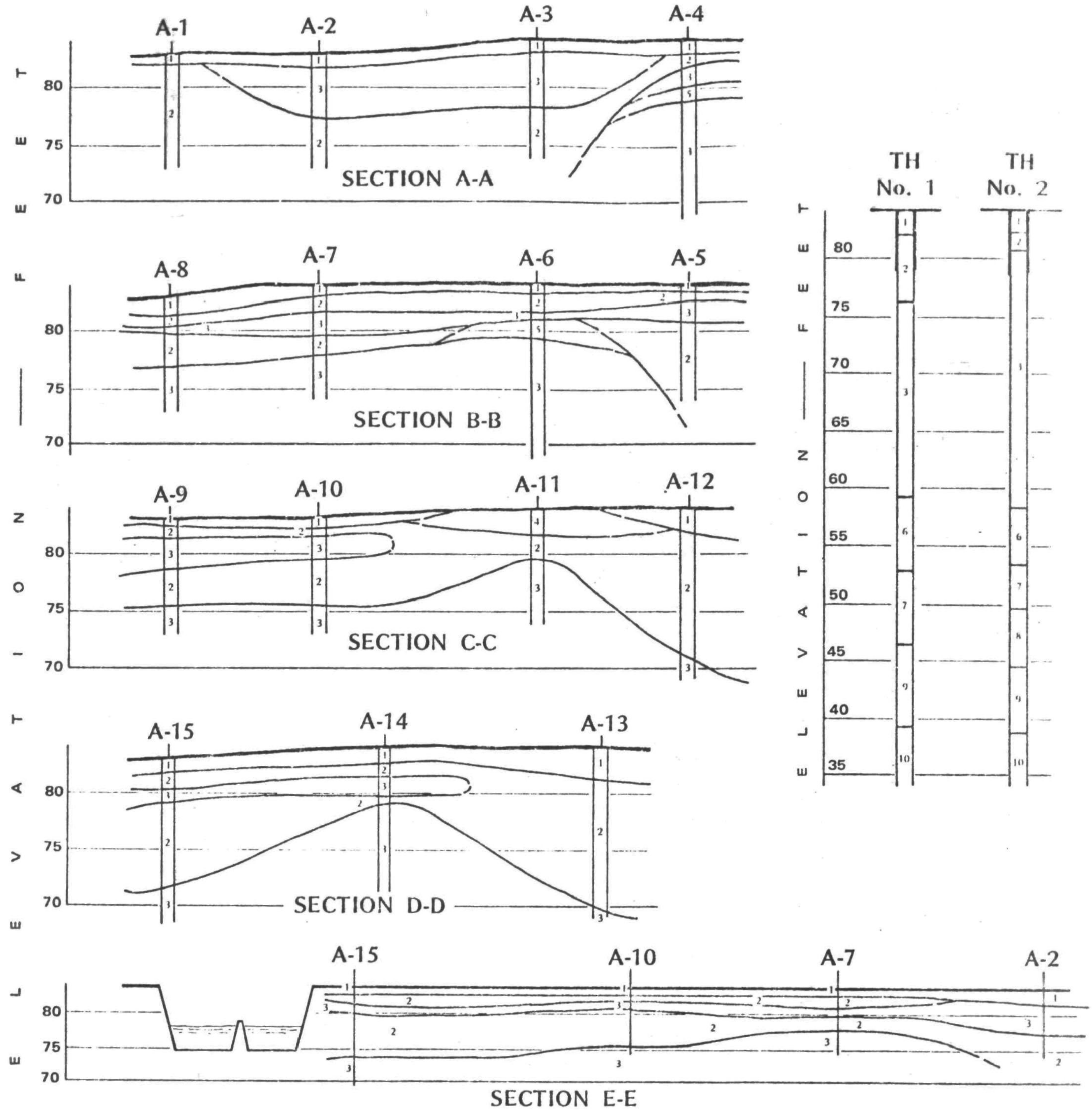
See Figure 39 for cross sections

— — — Ground water table contours at date of borings.
——— Topographic contours.

SOILS LEGEND

1. Light grayish brown to light brown fine sand--very loose to loose.
2. Dark reddish brown fine sand to dark brown fine sand (hardpan)--medium compact to dense.
3. Light brown to brown fine sand--loose to medium compact.
4. Dark brown to brown fine sand.
5. Dark brown to brown clayey fine sand.
6. Light brown to brown fine sand--medium compact to dense.
7. Greenish gray to gray fine sand--medium compact.
8. Gray clayey fine sand--medium compact.
9. Gray slightly silty to silty fine sand with finely broken shell--loose to dense.
10. Dark gray clay with finely broken shell--stiff.

FIGURE 38. SOIL BORING LOCATIONS



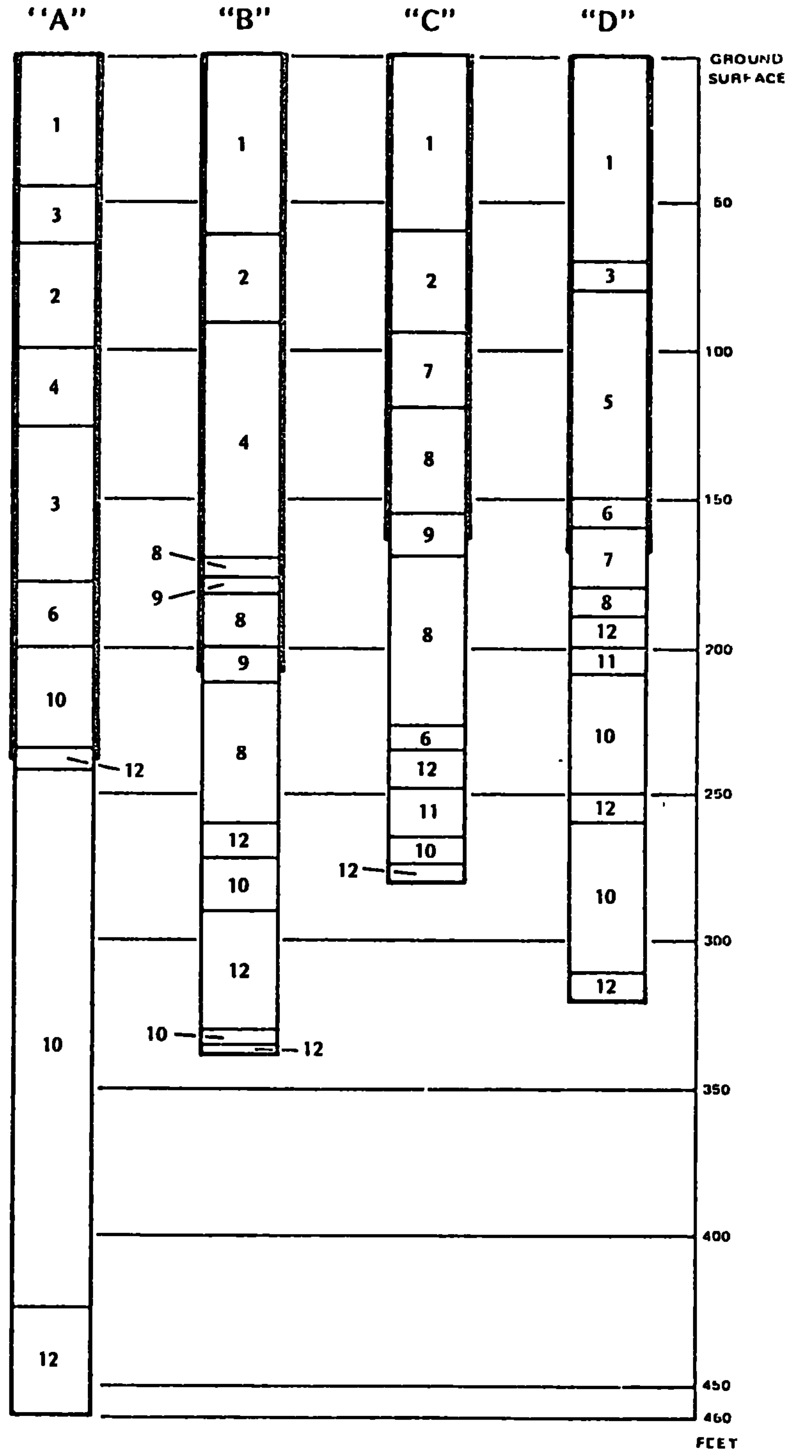
NOTE: See Figure 38 for soils legend.

FIGURE 39. CROSS SECTION OF SOIL BORINGS

cited a coefficient of permeability of 40 to 100 feet per month ($K = 4.7 \times 10^{-4}$ to 1.2×10^{-3} centimeters per second), typical of a fine sand.[38] This hardpan layer was intersected by the solid waste cells. It was underlain by loose sand having a permeability ranging from 700 to 1,000 feet per month.[2] Since solid waste cells intersected permeable layers of the top and bottom, lateral travel of leachate could occur if there was a sufficient hydraulic gradient. The natural site did not possess this gradient. The soil borings (Figure 39) and the deep well borings (Figure 40) indicated the clay and geologic components which restrict the vertical travel of leachate contaminated ground water.

Additional soils investigations were conducted at the site from 1971 to 1973. The objective was to better evaluate the passage of water in the soil. Surface sands at varying depths to about 18 inches were sampled at five well sites near the demonstration and control cells. The sands were light gray to medium dark in color. Sieve analyses showed about 97 percent passing a size 40 sieve, 75 to 85 percent size 60, but only 5 percent a size 140. These were fine to medium sands with some organics adding the black color. Permeability averaged 1.3×10^{-2} centimeters per second, characteristic of sand offering good drainage.[38] The specific gravity, voids ratio and porosity were 2.60, 0.84 and 0.46, respectively. Additional measurements of permeability were made along the cells and drainage system. Some samples were taken horizontally and some vertically at varying depths above the water table, to about 7 feet from the ground surface (just above water). Analyses were performed on 14 samples, six of light colored fine sands, eight on hardpan type material. The permeabilities of the first ranged from 10^{-3} to 10^{-2} centimeters per second. The hardpan ranged from 10^{-4} to 10^{-3} centimeters per second. No differentiation was seen between the samples in the horizontal and vertical directions, thus the water percolation should take place equally well in each direction under adequate hydraulic gradient.

Samples were taken from the final cover of two cells to examine the same characteristics. In covering using pans and bulldozers, sands were mixed and compacted to some extent. They were not seeded immediately but were allowed to consolidate under the natural rainfall. The Demonstration Public Cell was completed and covered in October 1972. In April 1973, six months later, soil samples were taken from 12 grid points on the cover of the cell, which measured about 230 feet by 520 feet in area. Sample depths were varied in the two feet of final cover. Analyses indicated an average permeability of 3.1×10^{-3} centimeters per second compared to the 1.3×10^{-2} centimeters per second found for the surface sands at the well sites. The voids ratio and porosity averaged 0.66 and 0.40, respectively, compared to 0.84 and 0.46 previously cited. Mixing, placement, and consolidation resulted in a cover of slightly higher density and reduced permeability than the natural surface. The material still allowed ready passage of rainfall, and with only a 2 percent cover slope planned, little runoff should occur. One other cell, Demonstration Public Cell 2, covered in February 1973, was examined in May 1973. A three-sample average of cover properties showed a permeability, voids ratio, and porosity of 6.4×10^{-3} centimeters per second, 0.92 and 0.46, respectively, somewhat changed from original conditions. It appeared again in this more recent cover that permeability decreased but still allowed ready percolation.



LEGEND OF FORMATIONS

1	Sand
2	Sand and Shell
3	Clay and Sand
4	Shell and Clay
5	Sand, Shell and Clay
6	Hawthorn (soft)
7	Hawthorn (medium soft)
8	Hawthorn (medium hard)
9	Hawthorn (hard)
10	Limestone (soft)
11	Limestone (medium hard)
12	Limestone (hard)

NOTES

	WELL DEPTH	CASING DIA	CASING DEPTH	PIEZOMETRIC SURFACE
A	460'	6"	239'	41'
B	340'	4"	208'	40'
C	280'	4"	163'	40'
D	320'	4"	168'	45'

FOR LOCATIONS SEE FIGURE 32

FIGURE 40 DEEP WELL BORING DATA

Observation of the after effects of rain storms indicated that the site dried up rapidly except where a hardpan and mucky layer existed at the bottom of a cut. In that event water stood a few days. In other locations it readily disappeared through percolation, leaving a rapidly drying surface. An excellent example of the rapid drainage occurred March 26, 1973, when 1.25 inches of rain fell overnight. The site was almost dry the next morning during the visit of the attendees at the Solid Waste Management Seminar being held to discuss results of the landfill in Orange County and other locations. It was a fortunate occurrence and demonstrated the operability of the site under adverse conditions.

The foregoing analyses would seem to indicate that infiltration of water at the site should be high with water easily passing to the landfill, causing rapid saturation and subsequent leachate migration. As indicated in the literature review section, leachate was expected to develop and migrate rapidly in this sandy environment. However, the latter was not observed. When leachate was detected, it was restricted in horizontal travel and was found only in wells close by cells. It appears that a number of factors were acting: (1) the soils readily absorbed moisture; (2) a great amount of this moisture could have been lost back to the atmosphere by evapoiation from the upper permeable sands and from the fill; and (3) more water may have been required to reach field capacity than the minimum cited in the literature. The site is flat and subject to sun and wind which causes dry surface conditions and promotes rapid evaporation after short rains. No migration was observed in this demonstration cell area. In the control cells, however, leachate in wells at the cell perimeters was observed within one year after filling.

Another facet of interest was the horizontal travel of leachate from the cells. As indicated by the soils studies, the lower sands were relatively permeable. In the demonstration cell area, however, the ground water table was loweied by ditching. In this section leachate was not observed in the wells exterior to the cells or in the pond receiving drainage water from the cell area. Considering the foregoing discussion, it appears that leachate did not migrate from the cell area during the project life. That leachate was produced is shown by data of Wells 3 and 29 located within a demonstration cell. In the control cell section, wells near the perimeter of cells started showing leachate in July 1972. These control cells were constructed with bottoms below the natural ground water table. Hence the lower portion of the fill was saturated. Even though the soils were very permeable the small hydraulic gradient (1:150) minimized horizontal travel of leachate.

In summary, the environmental quality, geologic, and soils studies indicate that the site is acting like a flat saucer of sand and water. Water can percolate readily vertically and horizontally through the sands at the site, if a gradient exists. However, it appears that the water table of the area has such small gradients that horizontal travel is very slow. This is protective in that decomposition of organics can take place over a longer time. Further, dilution extending over a longer time should reduce average ion and compound concentrations in the outfall water. The Orange County experience reaffirms the importance of the preinvestigation of the hydrology, geology, and soils characteristics in selecting landfill sites.

Weather Monitoring

A weather monitoring station was established at the demonstration site for the continuous recording of precipitation and air temperature. A Belford Instrument Co., Model 595, tipping bucket with a Model 592-1 recorder and counter was used for precipitation measurements. The air temperature was monitored with a Bacharach Instrument Co., Temp-scribe, Model STA, seven day temperature recorder. Installation of these items occurred in July 1971. These data were recorded on a daily basis (Volume II, Table 25).

The normal rainfall for Orlando is 51.37 inches per year with the rainy season extending from June through September barring tropical storms in October. Normal rainfall and summary data are presented in Volume II, Table 26. During 1970 and 1971, the annual rainfall was 43.96 and 44.78 inches, respectively. These low annual rainfall values indicate a deficit of 7.41 inches in 1970 and 6.59 inches in 1971. Precipitation in 1972 (51.49 inches) increased over the previous two years to a normal condition and 1973 appears to be another year of average rainfall. The greatest amounts of rainfall in excess of average monthly values appeared in October 1971 and August 1972. Other months having rainfall of more than 3 inches above normal were February and November of 1972 and January 1973. October 1971 and August 1972 were also the two months of the project with the largest amount of precipitation (10.93 and 14.48 inches, respectively).

Normal monthly temperatures ranged from 63F to 84F during this period of study. Average monthly normal temperatures for Orlando are between 60F and 83F. A 20 degree difference between maximum and minimum daily temperatures was typical.

Student Involvement

A secondary goal of the solid waste environmental investigation set by the U.S. Environmental Protection Agency was to involve students at Florida Technological University in the sampling and analysis work. This had the objective of making more students aware of landfill and general environmental sampling and analysis practices, as well as improving their discipline competence. It also would assist in strengthening environmental engineering and science programs at the University. These were in addition to providing technical support in the data gathering phase.

Each faculty investigator employed several students on the project. In addition, a number of students were interested in facets of the environmental assessment and accomplished special topics investigations for the faculty involved. A total of twelve students were employed: three on microbiology, six on chemistry and three on environmental engineering topics. In addition, seven students accomplished special topics investigations: four in the chemistry area, two in microbiology and one in engineering. Thus, nineteen students accomplished tasks on the project. The twelve paid students worked directly on the analyses used in deriving the data tables in this report. Some student assistance was also paid for in administration of the grant to provide typing, xeroxing, and similar support.

Topics of the students doing work independently of grant funds included investigation of separation of acid and base soluble lignin fractions in ground water, ultraviolet and visible absorption spectra of water soluble lignins, and a literature survey of lignins and natural ground water contaminants. Other subjects examined included the characteristics of a microorganism isolated from Well 3, a very heavily contaminated water. The objective was to establish an indicator organism, if possible, which could be correlated with leachate contamination. A second microbiology student studied the survivability of *E. coli* and *Staph. aureus* in natural ground waters from the sanitary landfill area. Survivability exceeded 14 days though numbers decreased with time. One engineering student examined the hydrology of the landfill site and attempted to establish a mathematical correlation between rainfall and ground water levels for future prediction of ground water levels. At the time no site rainfall data existed, hence that at a nearby community was used. No correlation was established. Later rainfall and ground water level data at the site will offer opportunities for additional studies on correlation. All of these special topics investigations were directly beneficial to the environmental quality investigation and were done at no labor cost to the project though some laboratory supplies were used.

As with all investigations of this type, results have influenced instruction of students. Over the three years of the project, classes or individual students have made visits to the project from personal interest and as part of the classroom instruction. Class visits were by environmental engineers. The overall impact has been good and has been of direct assistance to the University's environmental education and research programs.

ECONOMIC ASSESSMENT

Initial capital outlay associated with the institution of the solid waste disposal system at the "Demonstration Landfill" resulted primarily from three types of expenditures. These were: (1) land acquisition including access road right-of-way, (2) purchase and/or overhaul costs of operating equipment and (3) site development. Additionally, there were engineering fees related to the development of permit applications, preliminary environmental assessment reports, and construction specifications. Due to the experimental nature of the "Demonstration Landfill" these consulting fees were greater than those associated with the development of a non-experimental facility. Engineering and consulting fees for this Demonstration Landfill are not representative for a typical landfill and therefore are not presented.

Land acquisition consisted of the purchase of the 1,500 acre site and the right-of-way for the access road from Curry Ford Road to the site. Equipment expenditures included the overhaul of County owned units and the purchase of units specifically for landfill use. Initially, the following equipment, owned by the County, was available for landfill use and required no capital outlay:

2 International TD-20 dozers (14 years old)
(One of these was traded April 1972 on a new TD-25C dozer)
1 International TD-15 dozer (14 years old)
1 Hough H90 front-end loader (6 years old)

Costs associated with site development included clearing, access roads, drainage and landfill facilities. Most of these costs were incurred on a one-time basis and were basically those associated with making the site available for landfill operations (Table 3). Construction and operating costs, as they accrued during the project, are tabulated separately following this initial costing data.

From June 1971 through June 30, 1973, the landfill site has accepted a total of 280,047 tons of solid waste, of which 92,649 tons were deposited in the "control cells", 140,492 tons in the "demonstration trailer cells", and 46,906 tons in the "public cells", as shown on Table 4. The "public cells" were used continuously from October 1971 through February 1973. "Control cells" and "demonstration trailer cells" were not used simultaneously. However, there were periods of transition from one type of cell to the other when "control" and "demonstration cells" were both in use at the same time.

Table 5 is a summary of equipment costs and operating times for the period July 1, 1972 through June 30, 1973. The utilization of some old or overhauled equipment has resulted in excessive downtime for repairs and is reflected in the relatively high operating costs in some instances. Servicing, parts and labor costs were obtained from County accounting records submitted monthly. Amortization schedules were computed as per "1971 Estimating Guide for Public Works Construction" by Dodge,[39] with salvage values ranging from 10 to 13 percent of purchase price, and interest rates of 7 percent. The amortized cost of the administration and maintenance facilities, 13 cents per ton, has not been included in the economic assessment calculations.

TABLE 3

SUMMARY OF INITIAL CAPITAL EXPENDITURES

Land Acquisition	
Landfill Site (1,500 acres)	$ 531,364
Access Road Right-of-Way	1,675
Total Land Expenditures	$ 533,039
Equipment Expenditures	
1 International TD-20 Dozer (14 years old) Overhaul cost April 1971	$ 7,000
1 Rex Trashmaster Compactor (6 years old) Modification cost January 1971	7,000
Subtotal overhaul/modification costs	$ 14,000
1 Northwest 95 Dragline (3 cu. yd.) (Purchased August 1971)	$ 127,000*
1 International Harvester EC-270 Scraper, Self-propelled (21 cu. yd.) (Purchased April 1970)	67,717
1 International TD-25 C Dozer (Purchased April 1971)	65,757
1 International TD-25 C Dozer (Purchased April 1972)	61,988
Subtotal purchased equipment costs	$ 322,462
TOTAL EQUIPMENT COSTS	$ 336,462
Site Development Costs	
Site Clearing - 50 Acres	$ 9,258
Roads	
Access road (3.1 miles), entrance fencing and gate erection.	263,989
On-site roads and staging area. Clearing, grubbing, filling, and road work.	90,801
Subtotal for roads	$ 354,790
Drainage	
Outfall canal (2.7 miles)	$ 40,960
On-site drainage, Pond A	19,160
Subtotal for drainage	$ 60,120

TABLE 3 (CONTINUED)

Buildings and Facilities	
Concrete block office building with sanitary facilities, lounge and storage room (air-conditioned and heated). Concrete floored, prefabricated metal service and maintenance building with 3 bays for equipment servicing, 2-post lift, air compressor, 20-ton overhead bridge hoist. Scalehouse, pump house and pump, chlorinator room, metal storage building, high pressure pump (5 gpm - 1,000 psi) for trailer washing, washrack, fuel storage area and pump.	$ 134,580
Truck scales (50-ton capacity)	9,712
Six-inch potable water well	2,119
Telephone lines to site	3,600
Subtotal for buildings and facilities	$ 150,011
Total Site Development Costs	$ 574,179
TOTAL INITIAL CAPITAL OUTLAY	$1,443,680

*Actual price of $114,267 included a $12,733 allowance for trade-in of a 3/4 cu. yd. American Dragline

TABLE 4

SOLID WASTE DISTRIBUTION
JUNE 1971 THROUGH JUNE 1973

(Tons)

PERIOD	Control Cells								Demonstration Cells				Public Cells	Total Deposits
	CC 1	CC 2	CC 3	CC 4	CC 5	CC 6	CC 7	CC 8	CT 0	CT 1	CT 2	CT 3	CP 1, 2	
1971														
June	—	—	—	—	—	—	—	—	—	—	—	—	—	—
July	—	—	—	—	—	—	—	—	—	—	—	—	—	—
August	—	—	—	—	—	—	—	—	—	—	—	—	—	—
September	—	—	—	—	—	—	—	—	15000	—	—	—	—	15000
October	2352	—	2352	—	—	—	—	—	4500	—	—	—	1533	10737
November	3005	—	3005	—	—	—	—	—	2300	—	—	—	1545	9855
December	2796	—	5000	—	—	2000	—	—	—	—	—	—	1748	11544
1972														
January	1900	—	2921	—	—	2921	—	—	—	—	—	—	2156	9898
February	—	4274	—	—	—	6000	—	—	—	—	—	—	1470	11744
March	—	1300	—	700	—	4905	—	—	—	3452	—	—	2403	12760
April	—	—	—	—	—	—	—	—	—	10436	—	—	3750	14186
May	—	—	—	—	—	—	—	—	—	8985	—	—	3131	12116
June	—	—	—	—	—	—	—	—	—	8241	—	—	3780	12021
July	—	—	—	—	—	—	—	—	—	8431	—	—	2583	11014
August	—	3606	—	2330	—	—	—	—	—	3468	—	—	2287	11691
September	—	1837	—	6489	—	—	—	—	—	—	—	—	2569	10895
October	—	—	—	4334	—	—	3579	—	—	—	—	—	2575	10488
November	—	—	—	—	31	—	8442	—	—	—	—	—	2139	10612
December	793	—	—	—	7609	—	699	—	195	—	—	—	2665	11961

TABLE 4 (CONTINUED)

SOLID WASTE DISTRIBUTION
JUNE 1971 THROUGH JUNE 1973

(Tons)

	Control Cells								Demonstration Cells				Public Cells	Total Deposits
PERIOD	CC 1	CC 2	CC 3	CC 4	CC 5	CC 6	CC 7	CC 8	CT 0	CT 1	CT 2	CT 3	CP 1, 2	
1973														
January	3664	—	—	—	3658	—	—	—	—	—	—	—	4041	11363
February	—	—	—	—	—	—	—	—	—	—	5501	—	6531	12032
March	—	—	—	—	—	—	—	147	—	—	19114	—	—	19261
April	—	—	—	—	—	—	—	—	—	—	16926	—	—	16926
May	—	—	—	—	—	—	—	—	—	—	17062	—	—	17062
June	—	—	—	—	—	—	—	—	—	—	10083	6798	—	16881
TOTALS	14510	11017	13278	13853	11298	15826	12720	147	21995	43013	68686	6798	46906	280047

TABLE 5

EQUIPMENT OPERATING COSTS
JULY 1, 1972 THROUGH JUNE 30, 1973

Equipment	Equipment Age 6-30-73	Maintenance Amortization*	Operating Hours	Down Hours	Utilization (Percent)	Operating Cost/Hr.**
Scraper	3 years	$17,132.15	1,744.0	1,592.5	52.3	$ 9.82
Compactor	7 years	$16,445.23	1,480.0	1,162.5	56.0	$11.11
TD-20 Dozer	15 years	$12,118.43	543.0	2,291.5	19.2	$22.32
TD-25C Dozer	2 years	$19,374.42	1,913.0	1,344.0	58.7	$10.13
TD-15 Dozer	15 years	$11,444.14	612.0	737.5	45.3	$18.70
Dragline	2 years	$16,472.81	753.0	255.0	74.7	$21.87
Service Truck	1 year	$ 2,506.92	2,432.0	128.0	95.0	$ 1.03

* Servicing (parts and labor and fuel) includes actual expenditures for the one year period. Amortization schedule computed as per "1971 Estimating Guide for Public Works Construction" by Dodge, with 7% interest rate and salvage values ranging from 10-13 percent of purchase price.

** Does not include equipment operator's salary.

One measure of landfill operating effectiveness is the cost per ton of waste buried. For purposes of this report, it must be emphasized that only direct operating costs are considered in the cost comparison of "control cells" and "demonstration cells". A concerted effort was accordingly made to establish direct costs for typical cell construction and filling from the time of initial excavation to the placement of final top cover. All indirect costs associated with the landfill administration, such as watchmen, clerical, supervision, office supplies, and utilities were excluded. Added amortizations which applied only to "demonstration cell" construction included those pertaining to construction of the outfall canal, oxidation pond, periphery canal and drainage ditches. Amortized costs applicable to both types of cells during the filling process involved on-site roadways and the weigh station.

Cell construction direct costs are shown in Table 6 on the basis of cost per cubic yard of excavation. While essentially the same equipment was used for each type cell, in general, the slightly higher construction cost for the "demonstration type" (or dewatered cell) can be attributed to the additional amortized costs described above. Cell filling direct costs are shown in Table 7 on a basis of cost per ton of refuse buried. Significant differences appear in the other amortized costs and indications are that "control cell" wet conditions require more care and time expenditure for filling of an equivalent tonnage than for filling in a dry cell bottom condition.

Total direct cost comparisons for the construction and filling of each type cell, reflected in dollars per ton of solid waste as shown in Table 8, suggest the economy of operating in dewatered conditions. These costs are considered as typical for all operations to date, regardless of the specific cell designation. Significant cost reductions might have been realized had there been a possibility of utilizing newer equipment, thereby avoiding the maintenance expenditures usually associated with the older pieces.

In the consideration of direct costs only, of initial importance was the determination of actual operating costs associated with the heavy equipment, as they applied to individual cell construction, filling and covering. Likewise, of concern was the identification of all indirect costs such as those associated with management, water quality monitoring, weighmasters, watchmen, clerical and billing, some office supplies, maintenance and administrative vehicles. Once these indirect cost elements were separated, a concentrated effort was made to maintain precise data for total construction and filling periods of each type of cell. The cells chosen for cost comparison reflected construction and filling techniques typical of the type of cell. Additionally, it was felt that data for these cells was more reliable than the data obtained during the first year of the project.

Regarding heavy equipment costs, these were calculated on an annual basis. Thus, the calculation figures were more representative of actual operating costs. Extensive downtime with some pieces of equipment can be generally attributed to machine age. This caused the operating costs per hour to become inordinately high, and utilization less than desired. The County is in the process of replacing the compactor and an older dozer with new equipment.

TABLE 6

CELL CONSTRUCTION COSTS
DIRECT COSTS

(Typical Cell)

Cell Designation	Equipment Used	EQUIPMENT Oper. Hrs.	Oper. Cost/Hr.	Equipment Costs	PERSONNEL Man-Hrs. Expended	Wages Paid	Other* Amortized Costs	Total Direct Costs	Excavation Cubic Yards	Cost Per Cu. Yd.
Demonstration	Scraper	417.0	$ 9.82	$4,094.94	720.0	$2,412.00				
Trailer (CT 1	Dragline	66.0	$ 21.87	$1,443.42	80.0	$ 242.00	$1,056.00	$9,563.84	53,925	$0.177
Typical)	Serv. Truck	66.0	$ 1.03	$ 67.98	99.0	$ 247.50				
Control	Scraper	87.5	$ 9.82	$ 859.25	211.0	$ 706.85				
(CC 8 Typical)	Dragline	87.0	$ 21.87	$1,902 69	130.5	$ 413.25	—	$4,092.36	26,960	$0.152
	Serv. Truck	44.0	$ 1.03	$ 45.32	66.0	$ 165.00				

*Amortizations of outfall canal, oxidation pond, periphery canal and drainage ditches. These costs are not applicable to Control Cell construction/operations.

TABLE 7

CELL FILLING COSTS
DIRECT COSTS

(Typical Cell)

Cell Designation	EQUIPMENT Equipment Used	Oper. Hrs.	Oper. Cost/Hr.	Equipment Costs	PERSONNEL Man-Hrs. Expended	Wages Paid	Other** Amortized Costs	Total Direct Costs	Waste Deposited (Tons)	Cost per Ton
Demonstration Trailer (CT 1)	Scraper	139.0	$ 9.82	$1,364 98	259.0	$ 867.65				
	Compactor	184.0	$11.11	$2,044.24	224.0	$ 739.20	$3,748.00	$33,382.69	39,545	$0.844
	TD-15 Dozer	61.0	$18.70	$1,140.70	69.0	$ 227.70				
	TD-20 Dozer	326.0	$22.32	$7,276.32	386.0	$ 1,273.80				
	TD-25 Dozer	830.0	$10.13	$8,407.90	890 0	$2,937.00				
	Service Truck	240.0	$ 1.03	$ 247.20	360.0	$ 900 00				
					960.0*	$ 2,208 00				
Control Cell (CC 7)	Compactor	153.0	$11.11	$1,699 83	178 0	$ 587.40				
	TD-15 Dozer	23.0	$18.70	$ 430.10	27.0	$ 89.10	$1,498.00	$11,464.70	12,021	$0.954
	TD-20 Dozer	117.0	$22.32	$2,611.44	142.0	$ 468 60				
	TD-25 Dozer	195.0	$10.13	$1,975.35	220 0	$ 726 00				
	Service Truck	96.0	$ 1.03	$ 98.88	144.0	$ 360.00				
					400 0*	$ 920 00				

Note: Fill time for CT 1 was 5 months; for CC 7, 2 months

*Spotter man-hours
**On-site roads and weigh station amortizations

TABLE 8

COST COMPARISON
DEMONSTRATION VS CONTROL CELLS

Direct Costs Only

Cell Designation	Construction	Filling	Total Cost	Tons Waste Delivered	Overall Cost per Ton
Demonstration Trailer Cell (Dewatered)	$9,563.84	$33,382.69	$42,946.53	39,545	$1.09
Control Cell (Watered)	$4,092.36	$11,464.70	$15,557.06	12,021	$1.21

Overall operating costs considering both "direct" and "indirect" landfill costs derived from actual, budgeted and estimated data on a fiscal year basis are as follows:

TABLE 9

TOTAL OPERATING COSTS
(direct and indirect)*

Fiscal Year	Expenses	Tons Deposited	Cost Per Ton
10-1-71 - 9-30-72	$461,296**	138,461**	$3.33
10-1-72 - 9-30-73	$393,492+	178,000++	$2.21
10-1-73 - 9-30-74	$409,344†	228,000†	$1.79

*Does not include Debt Service, approximately $150,000/yr.
**Actual total expenses and tonnages
+Budgeted amount
++Estimated tonnage (actual 160,943 tons through August 30, 1973)
†Fiscal year projections

For FY 1972-1973, the significant reduction in cost per ton was due in part to the increased tonnages delivered to the landfill upon closing the Porter facility in February 1973, with associated minimal increases in expenditures to accommodate the approximated 6,000 tons per month of added waste.

Of interest to the project was to demonstrate that the added cost of site improvements and cell construction in a high water table area to protect water resources was acceptable in relation to costs of alternate available methods such as incineration. Incineration costs were developed utilizing limited available information on the construction and operation of incinerator complexes which incorporated measures for pollution control of flue gases. The available information gave primarily order of magnitude quantities and costs. Accordingly, many assumptions had to be made in developing costs for an incinerator of comparable capacity to the landfill facilities. The assumptions used are given as follows:

1. Incinerator sizing (capacity) was made on the basis of weekly tonnages delivered.

2. Initial need was for two 250-ton per day furnaces, with provision to expand to four 250-ton per day units by 1990. Volumes projected were 2,300 tons per week initially and 5,000 tons per week by 1990.

3. A three-shift, five-day week, 24-hour day operation was required.

4. The present landfill site area was chosen for location of the incinerator.

5. Water needs were satisfied from a deep well system within the site.

6. Pollution control equipment utilized were multiple cyclones and electrostatic precipitators.

7. Salary and wage computations included fringe benefits.

8. Maintenance and repairs costings calculated at 5 percent of capital costs.[40]

9. Water-wall furnaces with spray cooling of flue gases were used. There was no sale of steam.[41]

10. Assumed 15 percent downtime for repairs.[42]

11. Non-incinerable waste was 20 percent by volume of the total waste.[42]

12. Average capital cost for building and furnaces (1968) less pollution control equipment was assumed at $6,150 per ton.[42] This was adjusted to the 1973 cost index of 161 to reflect a cost of $9,900 per ton capacity.[43]

13. Utilities costs were calculated at $0.75 per ton incinerated.[42]

14. The storage pit handled 1.5 times the daily tonnages.[42]

15. Cost of cyclones and their erection was adjusted to 1973 cost index of 147.[42,43]

16. Cost of electrostatic precipitator and erection as given by manufacturer based on current prices and rates.[42,44]

17. Electrical power costs at prevailing rates in the area.[45]

18. A tentative incinerator personnel schedule was established consisting of three shifts: the first shift consisted of 1 supervisor, 1 foreman, 2 clerical, 1 crane operator, 2 firemen, 3 laborers; the second shift consisted of 1 foreman, 1 crane operator, 1 fireman, 2 laborers; and the third shift consisted of 1 foreman, 1 crane operator, 1 fireman and 2 laborers. For residue disposal operations, first shift would consist of 2 drivers, 1 equipment operator; second shift, 2 drivers; and third shift, 1 driver.

The calculated cost was $11.36 per ton, Table 10, which includes the initial and operating costs of a landfill facility for disposal of incinerator residue and noncombustible materials.

TABLE 10

INCINERATOR CONSTRUCTION AND OPERATION COSTS

First Year Capital Expenditures		
Land Area		
Facility (20A @ $350/A)	$	7,000
Landfill (200A @ $350/A)		70,000
Right-of-way costs		1,700
Access road construction		264,000
Land clearing and drainage		10,000
Water well supply		2,100
Telephones		3,600
Subtotal Costs	$	358,400
Disposal Equipments		
Front-end loader (1 @ $27,000)	$	27,000
Dump truck - 5 ton (2 @ $15,000)		30,000
Subtotal Costs	$	57,000
Structural		
Basic building and furnaces	$	5,000,000
Cyclone purchase and erection		92,200
Electrostatic precipitator purchase and erection		262,500
Subtotal Costs	$	5,354,700
Total First Year Capital Costs (Include Engineering and Contingencies)	$	5,770,100
Annual Operating Costs		
Incinerator and Disposal Complex		
Salaries and Wages (23 personnel)	$	169,500
Utilities (@ $0.75/ton incinerated)		89,700
Maintenance and Repairs		
Incinerator facility (5% cap. cost)		268,000
Disposal equipment		6,300
Supplies and materials (est.)		4,500

Air Pollution Equipment	
Utilities (Elec. @ $0.0195 KWH)	6,300
Depreciation (S.L.)	
Incinerator facility	225,600
Disposal equipment	11,400
Debt Service (17 years at 7%)	577,600
Total Annual Operating Costs	$ 1,358,900
Tons Delivered to Incinerator	119,600
Total cost/ton delivered, incinerated and/or processed for landfill disposal	$ 11.36

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APPENDIX

LABORATORY PROCEDURES

Chemical Procedures

Reagent Preparation. Proper preparation of reagents is the foundation of meaningful and accurate analytical procedures. Maximum care must be taken in preparing reagents, especially those which are primary standards and whose strength cannot be easily checked. When required for weighing a specific quantity, reagent chemicals are dried at 103C before weighing. Deionized water is used in the preparation of all reagents. Specific instructions for the preparation of reagents are found in the 13th edition of *Standard Methods for the Examination of Water and Wastewater.* *

pH. pH is determined in the laboratory by the Glass Electrode Method as described in *Standard Methods.* A line operated Sargent Expanded Scale pH meter is used in this determination. A Sargent combination glass electrode containing a saturated solution of potassium chloride is used as the sensing element. The normal limits of accuracy reported for this method are ± 0.1 pH unit.

Alkalinity. Total alkalinity is determined in accordance with the procedure described in *Standard Methods.* End point is determined potentiometrically by titrating to a pH of 4.5. This method is free of interferences due to residual chlorine, color and turbidity. Accuracy is reported to be ± 3 mg/l expressed as $CaCO_3$ using this method.

Acidity. Acidity is determined in accordance with procedures described in *Standard Methods.* The analysis is carried out by titrating the alkalinity with a standard sodium hydroxide solution to a pH of 8.3 as determined potentiometrically. Selection of this method was based on the elimination of residual chlorine, color and turbidity interferences.

Suspended Solids. Total suspended solids are determined by sample filtration through a glass filter pad. The glass fiber pads used are 2.1 cm glass fiber filters, grade 934AH, manufactured by Reeve Angel, Clifton, New Jersey. During filtration, the filters are supported by Gooch crucibles. Samples are dried at 105C avoiding the volatilization of organic matter and the loss of chloride and nitrate salts. The procedure used is described in *Standard Methods.*

Ammonia Nitrogen. Ammonia nitrogen is determined according to the Nesslerization Method with the distillation of pH 7.4 into 0.02 normal H_2SO_4 as described in *Standard Methods.* A Bausch and Lomb Spectronic 20 is used unless concentrations are high. In that case, a titration determines the concentration using sulfuric acid and avoids interferences encountered when boric acid is used.

*American Public Health Association, American Water Works Association and Water Pollution Control Federation. *Standard Methods for the Examination of Water and Wastewater.* 13th ed. New York, New York, American Public Health Association, 1971.

Total Organic Nitrogen. Kjeldahl Method and Nesslerization Measurement, in *Standard Methods*, using a Bausch and Lomb Spectronic 20 measure color intensity. The distillation is done in 0.02 normal H_2SO_4.

Nitrate Nitrogen. Nitrates were determined in accordance with the modified brucine method as described in *FWPCA Methods for Chemical Analysis of Water and Wastes.* Method selection was based on its ability to correct for turbidity, color, salinity, and dissolved organic matter.

Nitrite Nitrogen. Nitrites are determined using the analytical procedure as described in *Standard Methods*. This method utilizes the diazotization of the nitrite ion with the color intensity being measured on a Bausch and Lomb Spectronic 20 colorimeter.

Dissolved Oxygen. Dissolved oxygen is measured in the laboratory with a Yellow Springs Instrument (Y.S.I.) D.O. Meter and the azide modification of the Winkler Method described in *Standard Methods.*

Biochemical Oxygen Demand. The 5-day biochemical oxygen demand (B.O.D.) is determined in accordance with the procedure described in *Standard Methods.* The initial and final dissolved oxygen levels are determined by the azide modification of the Winkler method described above.

Chemical Oxygen Demand (C.O.D.). The chemical oxygen demand is determined by the dichromate reflux method described in *Standard Methods.*

Metals. The metals were analyzed using a Perkin-Elmer 305 Atomic Absorption instrument utilizing the manufacturer's suggested methods. All are analyzed by atomic absorption except for calcium in which flame emission is used. Analytical wave lengths currently being used are: calcium, 4227A; magnesium, 2852A; sodium, 5890A; potassium, 7665A; iron, 2483A; copper, 3247A; zinc, 2138A; and aluminum, 3092A.

Chlorides. Chlorides are determined in accordance with the argentometric method described in *Standard Methods.* As of August 1972 (data not included in this report), the method was changed to the mercuric nitrate method due to its superior end point.

Sulfate. The turbidimetric method is used following the procedures of *Standard Methods.* This method was selected because of its ease and speed of determination over the gravimetric method.

Hardness. Total hardness is calculated using the concentrations of calcium, magnesium, iron, aluminum, and zinc as described in *Standard Methods.* This method was selected due to its accuracy and the availability of determinations by atomic absorption.

Phosphate. Ortho-phosphate concentration is determined in accordance with the stannous chloride method described in *Standard Methods.* This method provides good sensitivity. Color intensity is measured using the Bausch and Lomb Spectronic 20 at a wavelength of 690 millimicrons. The samples are filtered prior to analysis, to remove turbidity. Total phosphates are determined by this method after a persulfate digestion in an autoclave. This digestion was selected in order to get good digestion with minimum time.

Total Dissolved Solids. A settled sample is filtered through a sintered glass filter. Duplicate filtered samples of 100 milliliters are pipetted into a tared weighing dish. Following evaporation to dryness at 103C, samples are cooled in a desiccator and weighed. Total dissolved solids are also arrived at by the difference of suspended solids and total solids.

Volatile Dissolved Solids. Dried samples from the previous test are placed in a muffle furnace at a temperature of 600C for 30 minutes. The loss in weight corresponds to the volatile dissolved solids.

Hydrogen Sulfide. Sulfides were determined by the methylene blue photometric method as outlined in *Standard Methods.*

Organic Content. A Beckman DS-2A ratio recording spectrophotometer is used. The ultraviolet absorption spectrum, 190 to 360 millimicron wavelength is recorded for each water sample after suspended solids have been removed by centrifugation. The method used is that of Menzel and Vaccaro.* Conversion to estimated dissolved organic material is by the method of Armstrong and Bolach.** The visible spectrum, 360 to 800 millimicron wavelength, also was taken for color analysis and to relate color to organic contamination.

Organic Compounds. A Hewlett Packard, Model 7620A, gas chromatograph with dual flame ionization detector is used. Initially, direct injection of 10 microliters of water samples was done with negative results. Subsequently, 100 ml of water from each well was extracted with $CHCl_3$, the extract dried, then taken up in 30 microliters $CHCl_3$. The microliters were injected in the gas chromatograph for analysis.

Total Organic Carbon. A Beckman, Model 915, Total Organic Carbon Analyzer is used. The procedure is under development.

Linear Alkyl Sulfonates. Analysis used the methylene blue technique as described on pages 339-342 in *Standard Methods.*

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*Menzel, D.W., and R.F. Vaccaro. The measurement of dissolved organic and particulate carbon in sea water. *Limnology and Oceanography*, 9: 138-142, 1964.

**Armstrong, F.A.J., and G.B. Bolach. The ultraviolet absorption of sea water. *Journal of the Marine Biologist Association*, (United Kingdom), 41: 591-597, 1961.

Biological Procedures

Phytoplankten. Phytoplankton samples are quantified in a Sedgewick-Rafter cell using the strip counting method. The clump count is expressed as algae per milliliter. Live and dead diatoms are differentiated observing preparation of permanent diatom slide, using Hyrax mounting media (R.I. 1.65) following the procedure of Weber.* Chlorophyll-a and phaopigments (phaophytin, phaophorbide and chlorophyllide) are analyzed spectrophotometrically according to Lorensen's Method. The trichromatic method for chlorophyll analysis is also used following the method of the A.P.H.A. using appropriate modification for phytoplankton samples. All chlorophyll values are expressed in milligrams per cubic meter.

Periphyton. Periphyton analytical methods are the same as phytoplankton with the exception of a few variations in procedure. The four slides preserved in five percent formalin solution are scraped with a razor blade and the scrapings returned to the jar. Aliquots of this are used for diatom slide preparation, quantification and identification. The counts obtained are expressed in cells per square millimeter. The four slides placed in 90 percent aqueous acetone are used in chlorophyll analysis following the trichromatic method and the method for chlorophyll-a in the presence of phaopigments. Both methods employed are recommended by the A.P.H.A. The pigments are expressed in milligrams per square meter.

Macroinvertebrates. When the multiple-plate samplers are returned to the laboratory, each sampler is disassembled and scraped with a brush into a white porcelain pan for sorting. All specimens are collected for identification and quantification. The quantification is based on organisms per square meter. All organisms collected on the multiple-plate samplers and from qualitative samples are preserved in 95 percent ethanol. For both sampling methods a pollution index developed by Beck was applied as a tool for presenting water quality from the macroinvertebrate data. The Biotic Index was calculated from:

$$2 \text{ (Class I)} + \text{(Class II)} = \text{BI}$$

where Class I organisms are pollution intolerant forms and Class II organisms are moderately tolerant.

Total Bacterial Count. Aliquots of diluted or undiluted water samples are cultured in triplicate plates employing tryptone glucose extract agar (Difco), supplemented with yeast extract (Difco). Dilutions were prepared in either Tryptone Glucose Extract broth or 1 percent water.

*Weber, C.I. Methods of collection and analysis of plankton and periphyton samples in water pollution surveillance system. *Water Pollution Surveillance System Application and Development, No. 19*, 1966.

Pour plate techniques are used in obtaining colony counts. For determining the count of aerobic organisms representative pour plates are incubated at 30C for 48 or more hours. To determine the total count anaerobic organisms, the same medium is employed and the plates subsequently placed in Gas Pak anaerobic jars. Anaerobic conditions are produced by use of a Gas Pak anaerobic generator (BBL). The anaerobic jars are incubated at 30C for 7 days. Counts are made at the end of the incubation period. Since the usual sampling procedures in the field preclude protection of the fastidious anaerobic bacteria during sampling and delivery, the anaerobic bacterial counts probably represent facultative anaerobic and/or obligately anaerobic spore-forming bacteria.

Selection and Enumeration of Specific Types of Bacteria. To count sulfur-oxidizing bacteria, 2.0 milliliter volumes of water samples were plated in Thiobacillus Agar (Difco) and incubated at 30C for 7 days. For enumeration of sulfur-reducing bacteria, 2.0 milliliter volumes of water samples were plated in a selective medium designed for detection of *Desulfovibrio* species. These platings were placed in anaerobic jars and incubated anaerobically for 14 days at 30C.

Coliform Analysis. Most probably number analyses employing lactose broth tubes were used to detect coliforms. Alternate to the above method, both total coliform counts and fecal coliform counts are obtained by the *Standard Methods* filtration techniques using 100 to 200 milliliters of water for filtration. The medium used for total coliform counts is M-Endo broth (Difco) and m-FC broth (BBL or Difco) for fecal coliform counts. Filters placed on m-Endo broth are incubated at 35 to 37C for 24 hours while those filters plated on m-FC broth are incubated at 44.5C for 24 hours.

Enterococci. One hundred milliliters of a water sample are filtered by membrane filter techniques. Filters are placed in Enterococcus agar in millipore dishes. Plates are incubated for 24 to 48 hours at 35 to 37C.

Salmonella. To establish the possible presence of *Salmonella*, tetrathionate broth tubes are incubated with millipore filters through which was passed 200 milliliters of a water sample. After incubation at 41C for 48 hours, agar media of Bismuth Sulfite and SS are streaked to isolate organisms growing in the Tetrathionate broth. Isolates are subcultured to TS1 slants which are examined for biochemical characteristics of *Salmonella*.

Alternately, gauze pads are immersed at the three surface water stations for 5 days. The retrieved pads are placed in flasks containing 500 milliliters tetrathionate broth and incubated 24 to 48 hours at 41C. After incubation, isolation techniques are performed as described. If *Salmonella* are suspected they are subjected to numerous differentiation tests used to identify enteric bacteria.

Staphylococci. To detect and quantify Staphylococci, agar media of Mannitol Salt Agar, Phenylethanol Agar, Staphylococcus Medium 110, and Tellurite Glycine are inoculated with 0.1 to 2 milliliter portions of ground water samples. Alternately, water samples are filtered through membrane filters, with the filters being placed on m Staphylococcus broth. Inoculated materials are incubated at 37C for 24 to 48 hours.

Actinomycetes and Fungi. To isolate actinomycete organisms, 0.1 milliliter of each water sample is plated on Actinomycete Isolation Agar (Difco) and spread by sterile spreader. Counts of filamentous fungi are made by adding 0.1 to 0.2 milliliter of each water sample in Cooke Rose Bengal Agar. Inoculated materials are incubated at 30C for 4 or more days.

Limited Biochemical Characterization of Bacteria. Attempts are made to distinguish bacteria according to their capacity to degrade and utilize complex natural substrates. Examples of these substrates are: cellulose, starch, proteins, and lipids. From 0.1 to 2.0 milliliter of each water sample is inoculated on agar medium containing the above substrates and spread over the surface. Counts of organisms degrading these substrates are obtained and compared to total count studies.

Differentiation of Species Isolated on Total Count Platings. All distinguishable colonies detected on total count agar plates are streaked on Tryptone Glucose Extract agar for purification. Pure cultures of each different isolate are maintained in stock culture slants employing the above medium. Each isolate will be differentiated with biochemical characteristics of each being recognized. Anaerobic bacterial isolates are prepared by enriching for these organisms in cooked meat medium. Dilutions of enrichment cultures are plated by spreading on blood agar. Isolated colonies are purified on blood agar plates and maintained on blood agar slants or stored in cooked meat medium. Identifications are made according to procedures outlined by the Communicable Disease Center (Atlanta), anaerobic laboratory.

Studies of the growth characteristics of the predominant species of bacteria isolated from Well 3 water samples include preparation of a medium suitable for optimum growth of the organism. Incorporation of 25 percent (volume to volume) of water from Well 3 is routinely done. Citrate buffer is used to adjust the pH to the desired value. The base medium constituents are those provided in Tryptone Glucose Extract Agar.

Survival studies of pathogenic and/or resistant type bacteria are performed by introducing one milliliter of the selected organisms to 99 milliliters of water obtained from Well 3. The organisms employed in the study included *Salmonella typhimurium*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* (coagulase positive). A 24-hour culture of each organism is prepared, diluted 1 to 10, and one milliliter of the dillution is then introduced to 99 milliliters of the water sample. Initial pH measurement is obtained as well as the zero-time viable count. The inoculated water is stored at ambient temperature and sampled for surviving organisms each 24-hour interval by routine dilution and plating techniques. A final pH is taken at termination of experimentation. A second survival study is performed exactly as above except that the initial pH of the water from Well 3 is adjusted to a near-neutral pH.

Soil Procedures*

Sieve Analysis. Approximately 500 grams of soil are oven dried overnight at 105C and weighed. The sample is sieved in a U.S. Standard sieve series to determine size distribution.

Permeability. A Soiltest Model K-605 combination permeameter is employed, using a constant head technique.

Specific Gravity. A displacement technique using a 500 milliliters pycnometer is employed.

Voids Ratio. A measured volume of soil is dried overnight at 105C and weighed. Knowing the specific gravity, the voids ratio and porosity may be calculated.

*Lambe, W.T., Soil testing for engineers, John Wiley and Sons, Inc., New York, New York, 1958.

THE FOLLOWING PAGES ARE DUPLICATES OF ILLUSTRATIONS APPEARING ELSEWHERE IN THIS REPORT. THEY HAVE BEEN REPRODUCED HERE BY A DIFFERENT METHOD TO PROVIDE BETTER DETAIL

FIGURE 6 Cypress Stand in Swampy Area of Landfill Site Prior to Drainage Improvements.

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FIGURE 9. Entrance Landscaping and Sign, Orange County Sanitary Landfill.

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FIGURE 10. Entrance to the Orange County Sanitary Landfill.

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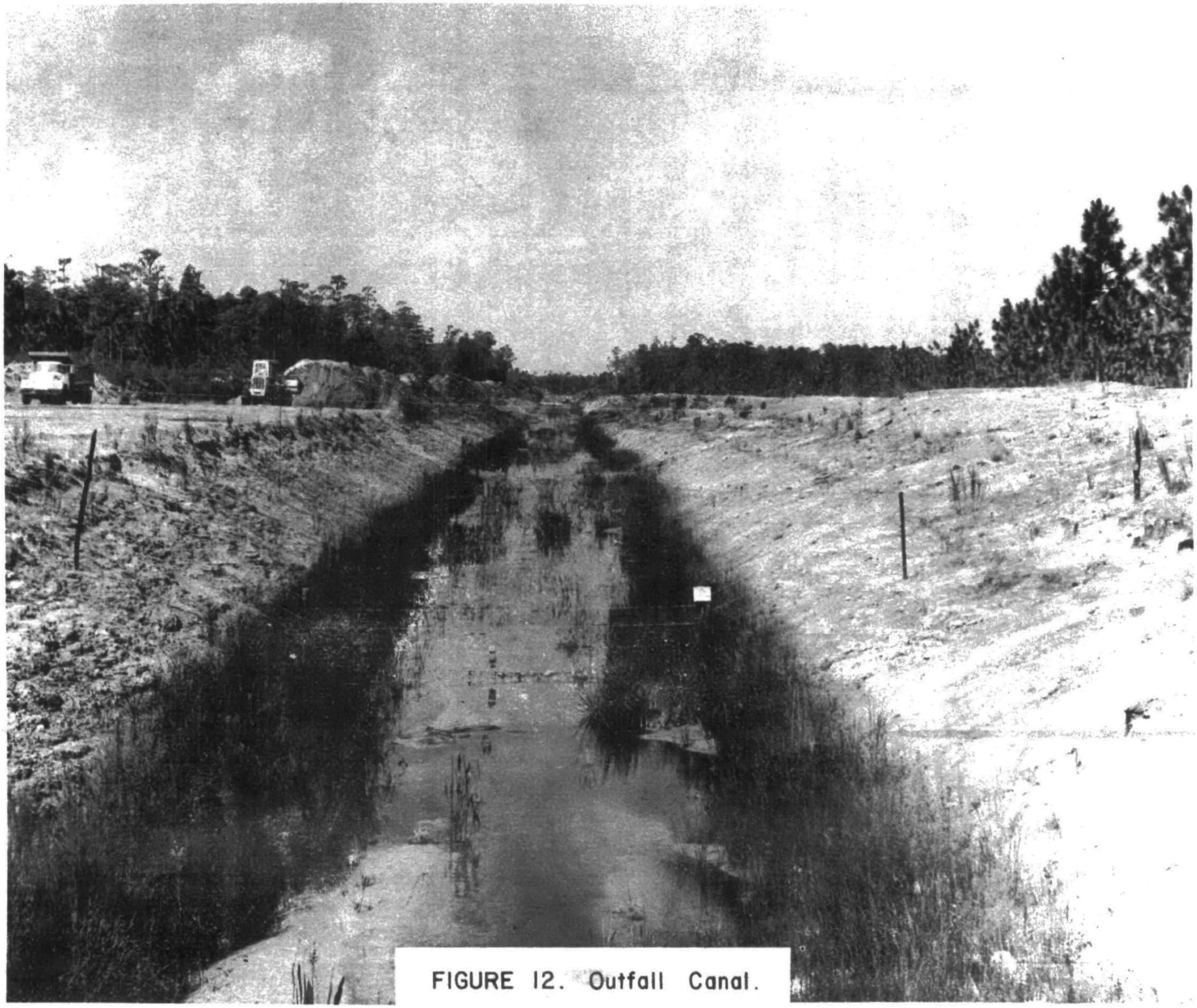

FIGURE 12. Outfall Canal.

FIGURE 13 Main Channel of the Little Econlockhatchee River.

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FIGURE 15. Drainage Pond A, Orange County Sanitary Landfill.

FIGURE 17. Landfill Office and Equipment Maintenance Building.

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FIGURE 18. Scale House, Orange County Sanitary Landfill.

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FIGURE 27 View of Typical Refuse Being Accepted at the Orange County Sanitary Landfill.

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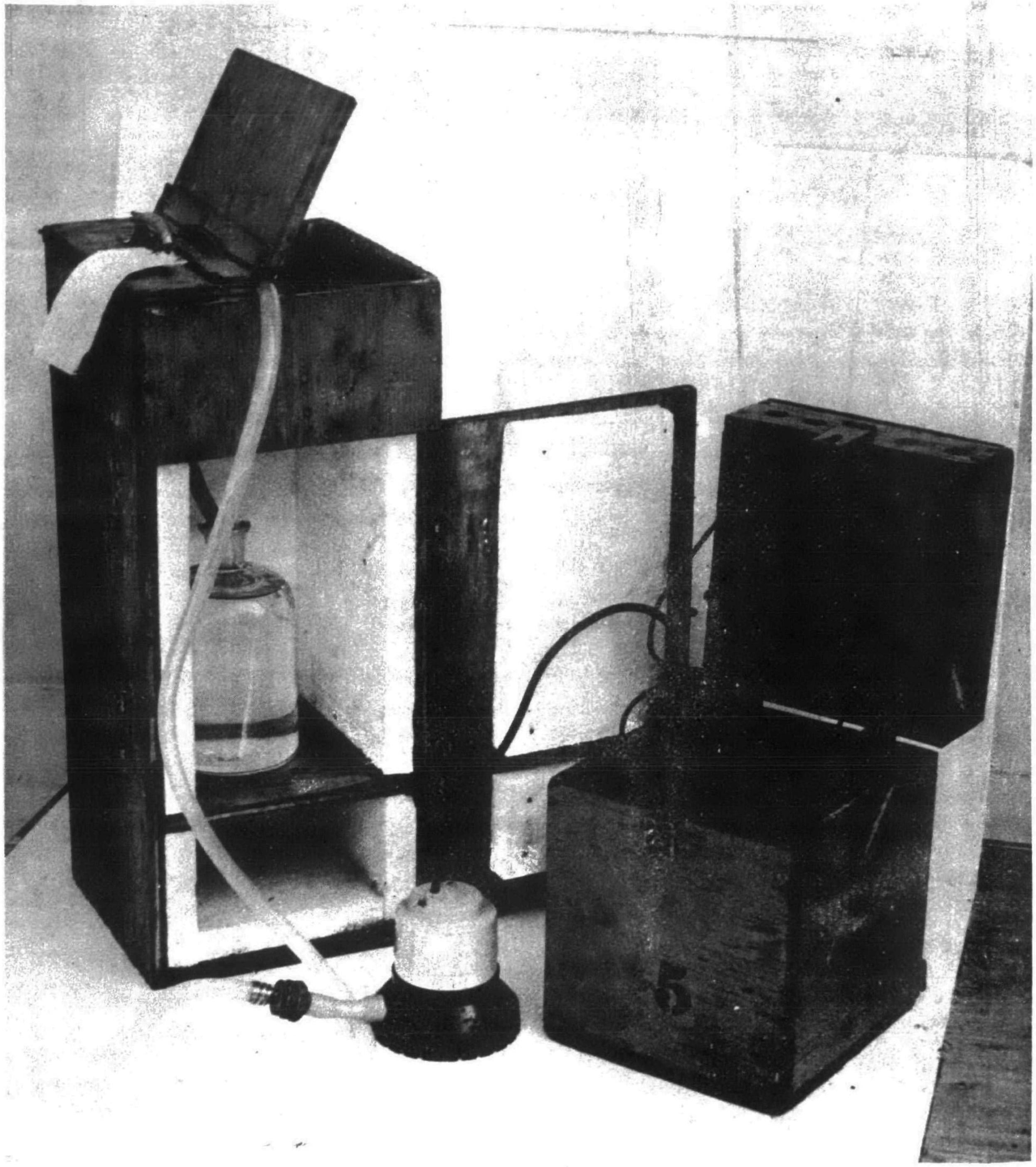

FIGURE 29. 24-Hour Composite Sampler for Surface Water Sampling.

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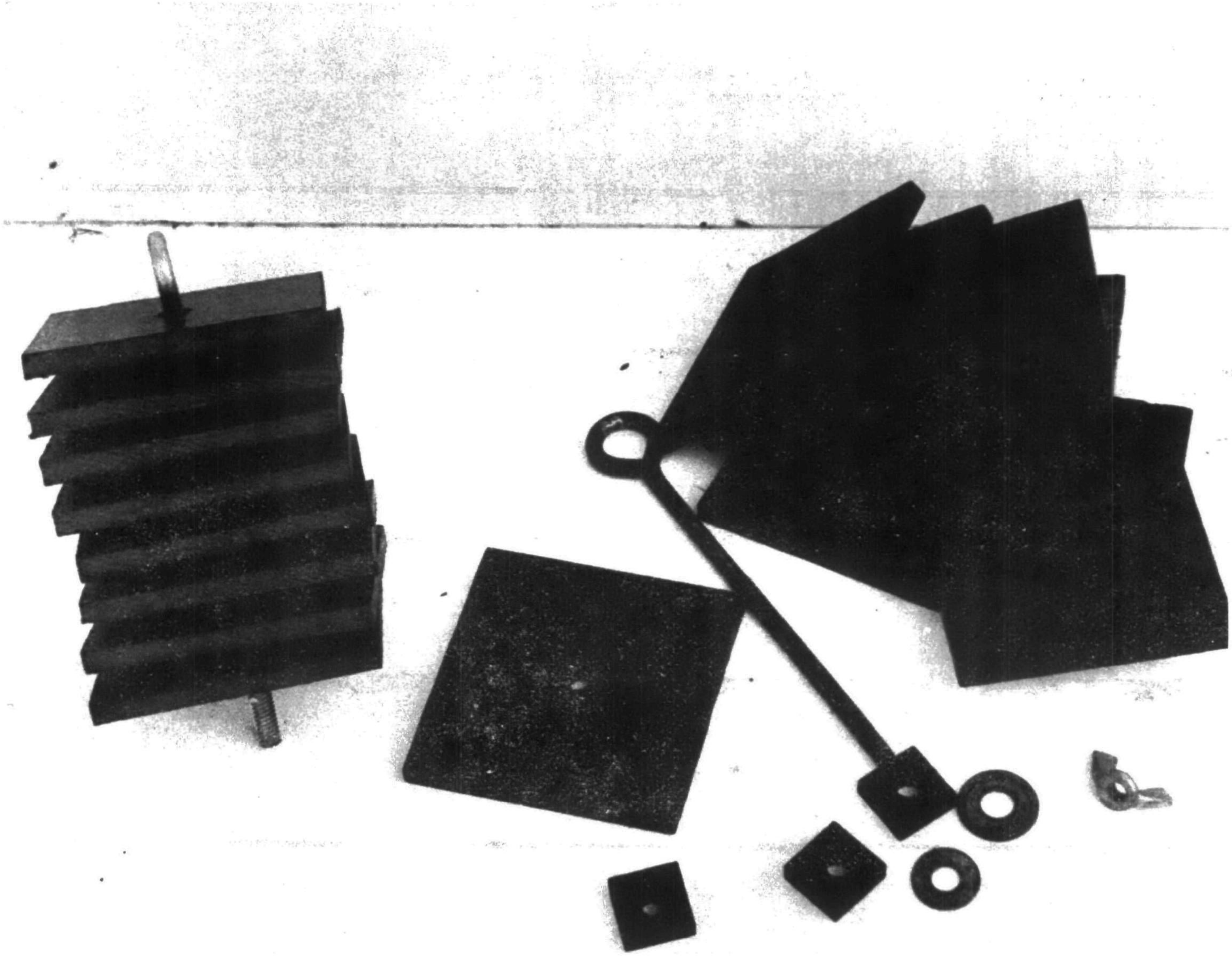

FIGURE 30. Multiple-Plate Macroinvertebrate Sampler.

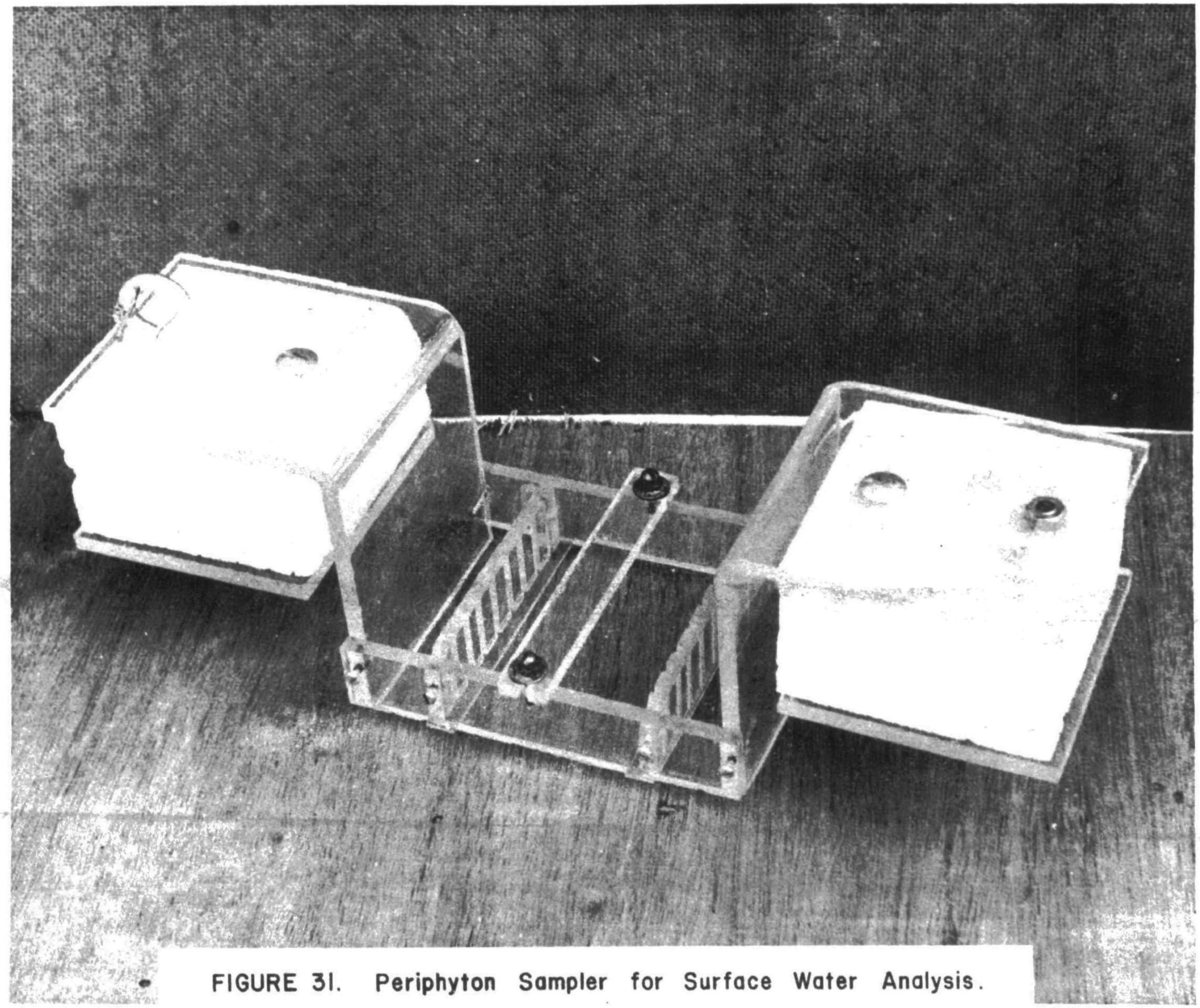

FIGURE 31. Periphyton Sampler for Surface Water Analysis.

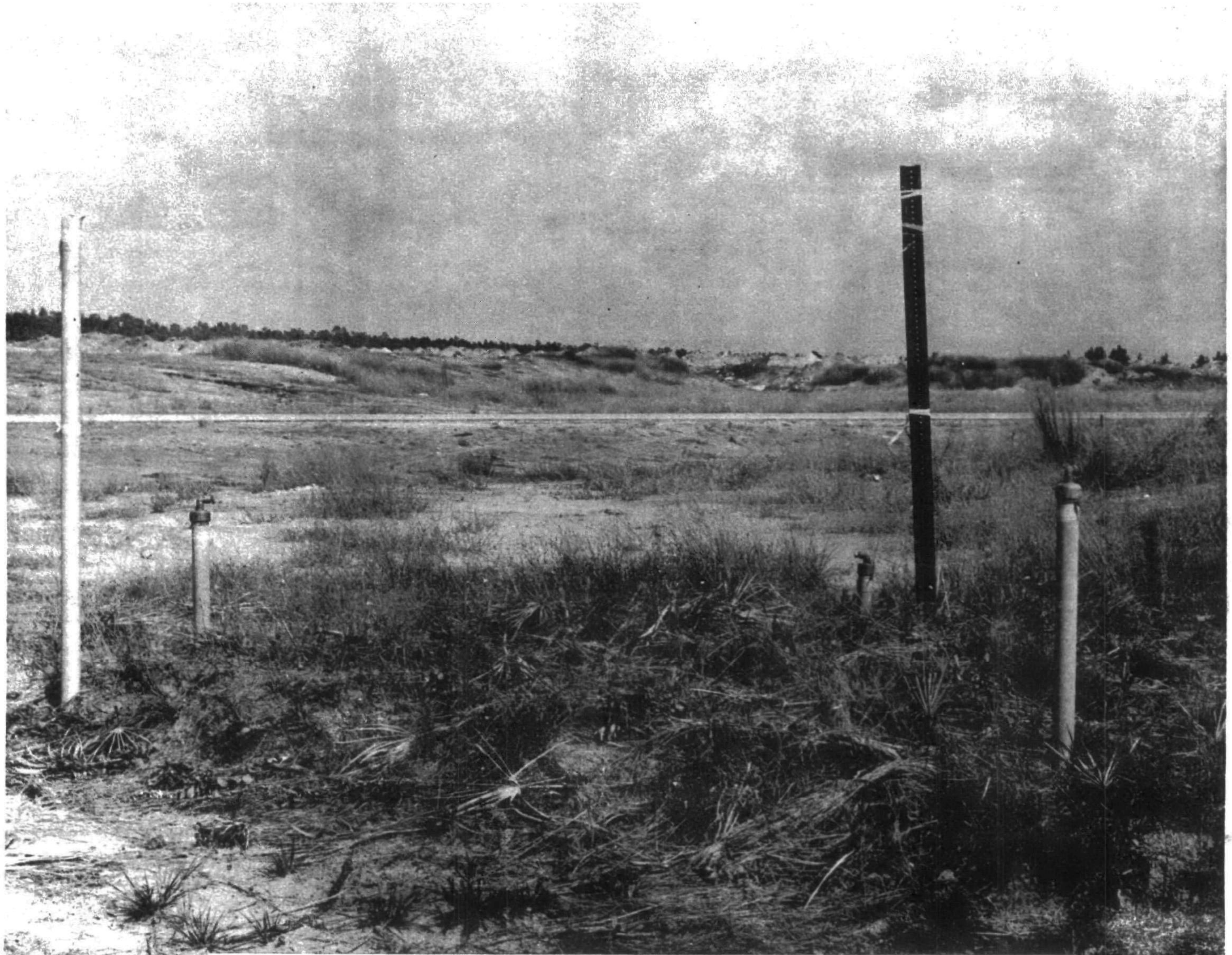

FIGURE 34. Shallow Well Cluster for Ground Water Sampling.

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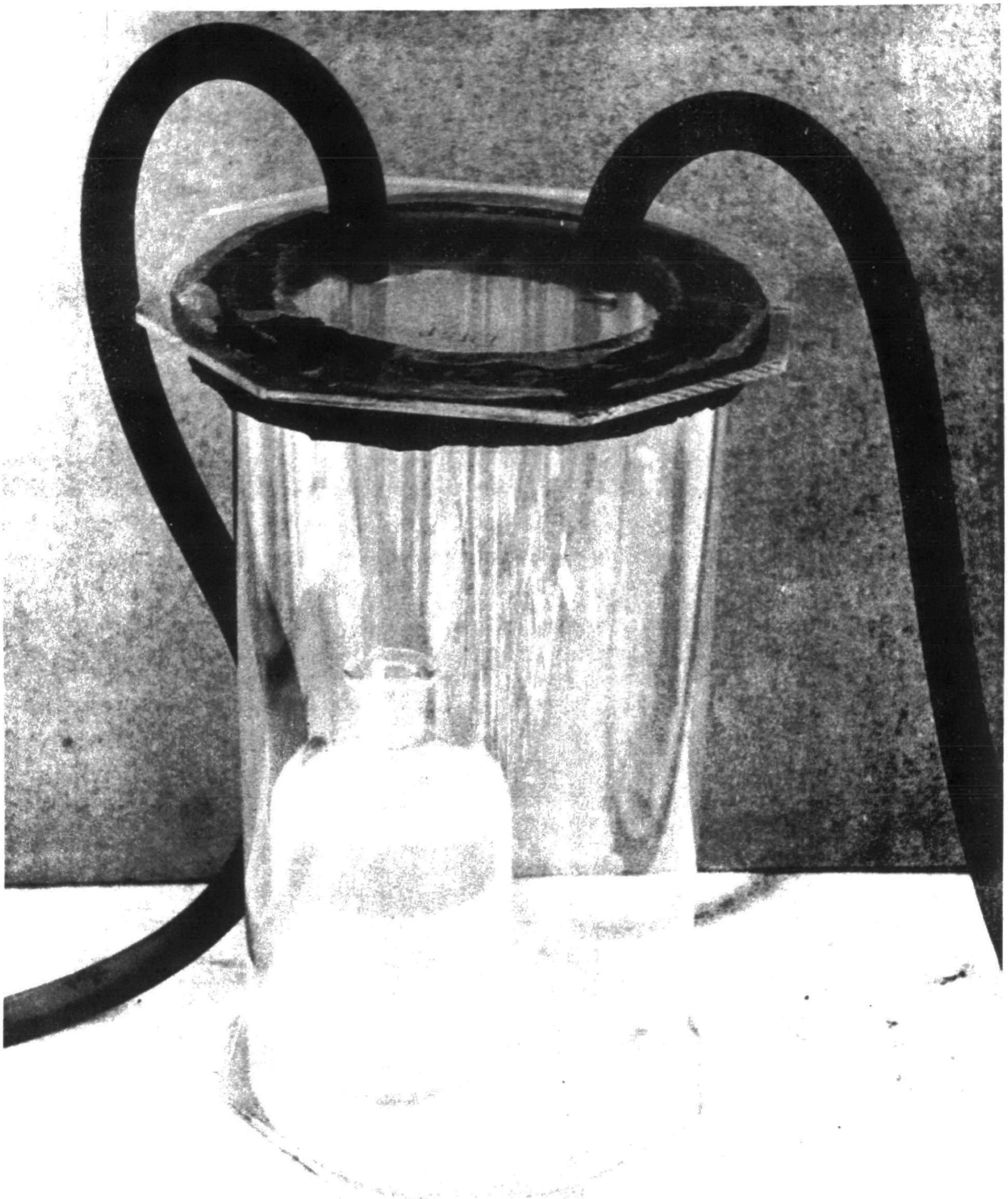

FIGURE 35. Vacuum Chamber for Shallow Well Sampling.