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# recovery of landfill gas at Mountain View

## engineering site study

a current report
on solid waste management

RECOVERY OF LANDFILL GAS AT MOUNTAIN VIEW

Engineering Site Study

This final report (SW-587d)
on work done under grant no. S803396 01
was prepared by John A. Carlson

U.S. ENVIRONMENTAL PROTECTION AGENCY

1977

ACKNOWLEDGMENT

I wish to thank the persons who have worked with me and made this report possible; namely, Richard Haughey, Robert McCafferty, and Don Powell.

—J.A.C.

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# INTRODUCTION

## Project Objective

The objective of the project was to determine how much methane gas can be withdrawn from a shallow sanitary landfill at a suitable quality and quantity to make it economically feasible for commercial use. The site of the sanitary landfill is Shoreline Regional Park in the City of Mountain View, California. The typical depth of the landfill is 40 feet.

## Locale and Background

The City of Mountain View in 1966 designed a 550-acre regional park in an area comprised mainly of flood plains, a sewage treatment plant, dumps, a pig farm, and a car-wrecking yard. The proposed park would replace the existing eye sores with a pleasingly aesthetic recreational park. The park landfill is comprised of 250 acres of sanitary landfill, 175 acres of earthfill (dikes, building pads, and roadways), 75 acres of lakes, and 50 acres of wildlife refuge. The refuse capacity of the site is 4,000,000 tons. Plate 1 shows the configuration of the landfill.

In the Shoreline Regional Park sanitary landfill, organic and inorganic refuse is placed in chambers that are lined with 5 feet of clay seal ($10^{-7}$ cm/sec permeability) on the sides and bottom. The refuse is compacted to 1,200 lbs/cubic yard and covered daily with a minimum of six inches of dirt. The final lift is covered with one foot of compacted clay soil plus a minimum of one foot of top soil. The bacteria, as they consume the organic material in the refuse, produce gases as waste products. With sufficient moisture, during the first year of decomposition, a relatively high proportion of oxygen in the fill promotes aerobic decomposition, which produces carbon dioxide, minimizing the production of methane. But, with time, as anaerobic conditions prevail, methane and carbon dioxide, with traces of other gases are produced in greater proportion. The concern for landfill gas arises from the potential hazard of methane accumulation and the ability of carbon dioxide to affect the quality of a water supply. Methane is a colorless, odorless hydrocarbon ($CH_4$) produced by biological decomposition of organic matter. Also known as marsh gas and in coal mines as firedamp, methane can be used as fuel or as a raw material in chemical synthesis. Alone, methane is not explosive, but when it accumulates at concentrations of 5 to 15% in air it is highly explosive. Since oxygen is virtually void in a densely compacted and sealed landfill when methane is produced, there is no danger of the fill exploding. However, if methane moves through the soil and accumulates in structures, it may cause explosive conditions.

Methane migrating through the sides or top of landfills may adversely affect plant life. Where disposal sites are located next to planted areas, or where parks and recreational areas are planned after disposal operations cease, the affect of methane on plant life is of particular concern.

Capturing landfill gas takes resource recovery another step beyond reclamation that is now carried out at a transfer station where metal, glass, and paper are recovered and recycled. Across the Country, there are many landfills that are sources of untapped energy. With each new landfill that is opened, a new source of energy is created. How these landfills are designed and how recovery wells are placed during the fill process can well affect the rate of recovery and total yield of each fill and, ultimately, the amount of energy available.

This report investigates the viability of producing methane gas from a shallow sanitary landfill. By measuring the landfill gas composition, gas withdrawal rates, decomposition temperature, pH, and the pressures within the refuse, this project attempted to provide the composition and quality of the landfill gas, optimum gas withdrawal, well spacing and gas withdrawal rates, potential gas production rate, and the affect of varying the water moisture content of the refuse on the gas production.

As part of the original proposal for the project, a section was included on the marketability of the landfill gas. But, it was decided that this study would be separate from this report. As a result of this project, a contract to sell the landfill gas to a utility company, Pacific Gas and Electric Company (PG&E), was executed.

## Approach

The project had three phases. In Phase 1, the project called for determining the effect of gas withdrawal rates on gas composition and the optimization of withdrawal rate for long-term production. In Phase 2, the Mountain View site was studied, in light of the data generated in the first phase, to determine total yield, production costs, and revenues (this phase was subsequently deleted from the project). In Phase 3, the effect of moisture and other factors upon gas production rates from the sanitary landfill was to be studied. This phase was discontinued at the time this report was finalized.

For Phase 1, the method used to obtain the above mentioned results was:

a. Construct two gas withdrawal production wells, designated 7A and 7B, in separate refuse chambers as shown on Plate 1. Each gas withdrawal well has two levels from which the gas was drawn, i.e., one from the bottom and the other from the middle of the landfill. The piping lead into a positive displacement pump which was belt-driven by a Volkswagon engine. The gas was discharged through a demister into a burning stack.

b. Construct 14 pressure monitoring wells around withdrawal well 7A and 16 pressure monitoring wells around withdrawal well 7B as shown on Plates 2 and 3. Each pressure point in each refuse chamber (28 for withdrawal well 7A, and 20 for withdrawal well 7B) was connected to a central monitoring board located in the compound area of the pump. The monitoring board simulated the field condition to minimize recording errors, and each pressure point had a separate valve which led to manometers.

c. Pump gas from the withdrawal wells at varying rates for a short period of time, and measure the composition of the gas and the pressure distribution in the landfill. The gas, over different time periods, was withdrawn from the bottom only, the middle only, and both the bottom and middle levels in the landfill. For the testing procedures used, refer to Chapter V, "Testing Procedures."

d. Once the optimum pumping rate was established, the well was continually pumped for 30 days to confirm the rate established by the short-term pumping. The gas was sampled at least twice a week to track the gas constituents.

For Phase 1, withdrawal well 7A was used as the primary source of information. Withdrawal well 7B was used to confirm the information obtained in well 7A.

For Phase 3, the method used to determine the effect of moisture on the landfill was essentially the same as Phase 1. Both withdrawal wells 1A and 1B were constructed exactly like well 7A and the refuse around well 1A was moistened with water.

Production well 1A was manipulated to determine the effect of moisture. Production well 1B was used as a control. Using the optimum withdrawal rate found in Phase 1, both wells were pumped for one week and the gas analyzed. This test was the basis for recording changes in the two wells over the testing time period. Water was then added to the refuse surrounding production well 1A equivalent to 10% moisture content of the refuse. The gas from both wells was constantly analyzed to determine the amount and timing of the effect of moisture of the refuse. At this point, it was determined that groundwater was entering the landfill at a different location in the landfill, and this phase of the project was discontinued. See Plates 1 through 3 for well cross sections and locations. Refer to Chapter V "Testing Procedures" for testing methods.

## CONCLUSIONS

The following are the basic results of the program. If the reader intends to use these results, it is suggested that Chapter III, "Discussion of Results" be read in order that the results are correctly applied.

### Landfill Gas Composition-Static Conditions

The composition of the landfill gas during static conditions varied in each part of the landfill. Table 1 depicts the variation in the gas composition in the landfill. The samples in Table 1 were taken prior to initiation of this project.

TABLE 1
WELL 7A
VARIATION IN LANDFILL GAS COMPOSITION
STATIC CONDITION
AT START OF PROJECT

| | Percentage of Constituents of Different Samples | | | |
|---|---|---|---|---|
| Wellpoint Identification | 7A-M6D | 7A-SM7 | 7A-SM4 | 7A-M7D |
| Methane | 61.69 | 45.65 | 23.52 | 3.18 |
| Carbon Dioxide | 37.00 | 36.50 | 29.92 | 4.73 |
| Nitrogen | 0.74 | 16.48 | 44.75 | 72.59 |
| Oxygen | 0.54 | 1.37 | 1.80 | 19.50 |
| Miscellaneous | 0.02 | ----- | 0.01 | ----- |

*Refer to Plate 2 for wellpoint locations.

### Withdrawal Rate/Radius of Influence and Landfill Gas Composition

A stable gas composition (44% Methane, 34% Carbon Dioxide, 21% Nitrogen, and 1% Oxygen) was obtained at a withdrawal rate of 50 cfm for a well 40-feet deep. The effective radius of influence for 50 cfm is approximately 130 feet.

### Total Gas Production Rate

The estimated total gas production rate, 150-acre site, 40-feet deep, is 7.5 mmcfd. Refer to Part F, "Calculation," of the Appendix for calculations or determining the total gas production rate.

### Effect of Moisture

Project was terminated too early to notice any affect. Groundwater was infiltrating into the landfill and was affecting the monitoring and pumping.

## DISCUSSION OF RESULTS

### Landfill Gas Composition-Static Condition

For the major portions of the landfill that were tested, the analysis showed the landfill was undergoing anaerobic decomposition. There were pockets that contained primarily air randomly spaced throughout. These pockets might have been due to an excessively dry section of refuse or might be a result in an error in the sampling procedures. Static condition samples were taken prior to and after withdrawing gas from the landfill at rates of 100cfm, 150cfm, 200cfm and 300cfm. The pumping was done from December 16, 1974 to January 7, 1975. The static condition tests were taken on December 13, 1974 and January 17, 1974. Please refer to the section "Data" of the Appendix for gas analyses for all static condition tests.

Plates 4 through 13 show the change in the distribution of gases in the landfill from December 13, 1974 to January 17, 1974. These Plates show that the landfill gas was drawn down and horizontally into the well. Inspection of the nitrogen and oxygen concentration on Plates 9 and 11 reveals the intrusion of air into the landfill at the higher withdrawal rates.

After withdrawal of gas, as a result of the short run tests, it appears that the concentrations of methane and carbon dioxide decreased and nitrogen and oxygen increased. From Table 2 it can been seen how the gas concentrations changed.

TABLE 2

AVERAGE CHANGE LANDFILL GAS COMPOSITION

DUE TO PUMPING

| Constituent | | Mean Value* | Range Wherein 99% of Readings Lie |
|---|---|---|---|
| Methane: | Before** | 45% | 27-63 |
| | After ** | 44% | 30-59 |
| Carbon Dioxide: | Before | 35% | 27-42 |
| | After | 32% | 25-40 |
| Nitrogen: | Before | 18% | 0-41 |
| | After | 21% | 2-40 |
| Oxygen: | Before | 1.7% | 0.1-3.2 |
| | After | 2.1% | 0.1-4.0 |

*Two samples, 7A-M5D and 7A-M7D, from before and three samples, 7A-M25, 7A-M4S, and 7A-M7D, from after are omitted from calculations due to probability of air contamination. Values in the Table were obtained by using the data from the analysis of the samples taken at static conditions before and after the short run testing.

**Refers to values taken before or after the short run tests.

Since the methane and carbon dioxide paralled each other, it is assumed that the landfill never reverted to the aerobic state. Under aerobic conditions, the carbon dioxide would have increased considerably and the methane would have decreaed to approximately zero. Intrusion of air into the landfill apparently only retarded the anaerobic decomposition. There might be two reasons for this. For one, the top soil and clay seal could have absorbed sufficient oxygen as the air passed through them such that the remaining oxygen was not enough to affect the anaerobic decomposition. On Plates 9 and 11, respectively, it can be seen that the nitrogen content increased substantially at the top of the landfill and there was only a minor change in the oxygen content. The other reason is that the majority of organisms in the landfill (at least near the top of the landfill) might be facultative due to the continuous passage of air and landfill gas in and out of the landfill as the atmospheric pressure changes. (Please refer to section "Gas Dynamics in Landfill" in the Appendix for a discussion on the porosity of the top clay seal and the affects of atmospheric pressure on the landfill.) The facultative organisms could tolerate the oxygen being drawn in by the pumping and would immediately recover to anaerobic decomposition when the pumping was discontinued after they utilized the oxygen in the landfill.

## Withdrawal Rate/Landfill Gas Composition

The gas composition varied as the withdrawal rate varied not due to exceeding the gas production rate by the anaerobic organisms, but due to the intrusion of air through the top clay seal of the refuse landfill. Plate 14 shows the variation in landfill gas composition as the gas was withdrawn at different rates. From Plate 14, it can be seen that a stable condition was reached at a withdrawal rate of 50 cfm. Table 3 gives the values for methane, carbon dioxide, nitrogen, and oxygen gas for every test taken during the time the gas was withdrawn at 50 cfm. Table 3 also gives a running average of values.

By inspecting Plate 14, the reader can see the interrelationship between the four major gas constituents. In general, methane and carbon dioxide paralled each other and decreased as the withdrawal rate increased. Nitrogen and oxygen increased as the withdrawal rate increased. Proportionately, the amount and variation of nitrogen was much greater than oxygen.*

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* In air, the ratio of nitrogen to oxygen is approximately 4 to 1. In the landfill gas, the ratio of nitrogen to oxygen varied but was approximately 20 to 1. The difference in ratios apparently means that as the air was drawn through the top soil, clay seal, and refuse, the oxygen was absorbed by these media and/or removed by microorganisms in the landfill.

TABLE 3

50 cfm Continuous Pumping

| Date | $CH_4$ | $CO_2$ | $N_2$ | $O_2$+Ar*** |
|---|---|---|---|---|
| May 22 | 41.42/41.42* | 35.75/35.75 | 21.89/21.89 | 0.94/0.94 |
| May 23 | 42.20/41.81 | 36.80/36.28 | 20.00/20.95 | 0.90/0.92 |
| May 27 | 43.70/42.44 | 33.60/35.38 | 21.30/21.06 | 1.40/1.08 |
| May 28 | 41.68/42.25 | 33.57/34.93 | 23.41/21.65 | 1.34/1.15 |
| May 29 | 41.38/42.08 | 33.42/34.63 | 23.51/22.02 | 1.69/1.25 |
| June 5 | 45.44/42.64 | 34.86/34.67 | 19.10/21.54 | 0.60/1.15 |
| June 6 | 45.65/43.07 | 31.66/34.24 | 21.40/21.52 | 1.28/1.16 |
| June 11 | 44.50/43.25 | 34.64/34.29 | 20.22/21.35 | 0.64/1.10 |
| June 13 | 45.25/43.47 | 34.65/34.33 | 19.38/21.13 | 0.72/1.06 |
| June 17 | 45.47/43.67 | 35.03/34.40 | 18.98/20.92 | 0.52/1.0 |
| June 20 | 46.49/43.93 | 30.73/34.06 | 21.34/20.96 | 1.44/1.04 |
| June 25** | 45.84 | 19.4 | 29.7 | 5.22 |
| June 27 | 44.92/44.01 | 35.02/34.14 | 19.58/20.84 | 0.48/1.0 |
| June 30 | 44.31/44.03 | 34.82/34.20 | 20.39/20.81 | 0.48/0.96 |

* Data/Running Average

** Sample not included in calculations due to high air content. Probable cause is contamination of the sample.

*** For ease and speed of analysis Argon was not separated from Oxygen. The Argon content is negligible.

At the withdrawal rate of 200 cfm, sufficient amounts of air were drawn into the landfill, as indicated by the increase in nitrogen from February 11, 1975 to March 2, 1975. By March 2, 1975, a sufficient amount of air was drawn into the landfill to affect the anaerobic condition of the landfill and it took 51 days for the landfill to recover.

On March 17, 1975, the withdrawal rate was reduced to 150 cfm. But, after one day, it was found that the landfill had not recovered and pumping was discontinued until April 23, 1975.

On April 23, 1975, the pumps were started at a withdrawal rate of 100 cfm. After eight days, the gas quality showed signs of deterioration. By 13 days, May 5, 1975, the quality was definitely down and the withdrawal rate was reset at 75 cfm on May 6, 1975.

At 75 cfm, the gas quality appeared to go down slightly. It was difficult to tell exactly what was happening since the PG&E gas chromatagraph was not working right and only partial results were being received. Refer to the Commentary on Plate 14. A different lab was used and the first results back for May 16, 1975, showed a drop in gas quality and the pump was stopped until May 17, 1975 where the pump was restarted at a withdrawal rate of 50 cfm.

In view of the tests before and after the test taken on May 16, 1975, and since this was the first sample taken by this new lab, the results of the sample taken on May 16, 1975 may indicate a poorer gas quality than which existed. This may mean that a withdrawal rate of 75 cfm might have produced a consistent gas quality.

The withdrawal rate of 50 cfm, set on May 19, 1975, provided a consistent gas quality of 44% $CH_4$, 34% $CO_2$, 21% $N_2$, and 1% $O_2$. Refer to Table 3. As the gas was pumped from May 19, 1975, to June 30, 1975, the gas quality was actually improving as indicated by the running average values in Table 3.

<u>Withdrawal Rate/Radius of Influence</u>

The gas withdrawal rate was varied from 0 to 300 cfm as shown on Plate 14. Plates 15 through 22 show the pressure distribution in the landfill at different rates and withdrawal levels. The curves were derived by plotting the measured pressures from the monitoring wells as shown on Plate 2. At first, the flow rate was determined by using the pump curve for the positive displacement pump. But the curve was too inaccurate at the low flows, so the graph in Plate 24 was established. Thereafter, consistent results were obtained for all flows, especially below 75 cfm, by establishing the appropriate negative pressure in the well for the desired flow rate. Plate 23 shows the relationship between the negative pressure head and radius of influence. The curve is a generalized formula, see formula (1) below, derived from the data.

Withdrawal rates above 200 cfm have a slightly greater radius than indicated by the curve and withdrawal rates below 200 cfm have a slightly smaller radius than indicated by the curve. Plate 24 shows the relationship between the negative pressure head at the well and the withdrawal rate. By combining the empirically derived formulas in Plates 23 and 24, i.e.,

If $\frac{h}{H_w} = 12.5/R^{1.25}$, Plate 23 (1)

and if $H_w = -\ 0.00039Q\ (Q + 133)$, Plate 24 (2)

then $hR^{1.25} = -\ 0.004875\ Q\ (Q + 133)$ (3)

The graph on Plate 25 shows the relationship between the withdrawal rate and radius of influence for different pressure contours in the landfill. As can be seen by Plates 23 and 25, there is no definite theoretical cut-off point where the well does not affect the landfill and natural phenomena prevents accurate field measurement. By using the chart in Plate 25, a negative 0.1 inches of water pressure was established for the effective radius of influence. At less than negative 0.1 inches of water pressure, the flow of gas is susceptible to varying localized pressure fluctuations due to atmospheric pressure changes and varying decomposition activity. These localized pressure fluctuations would direct the gases away from the well.

Total Gas Production Rate

The estimate for gas production of the entire site will be based upon the results of the long-term pumping of the landfill and the resulting radius of influence. From Plate 14, it can be seen that a flow of 50 cfm provided a stable and slightly increasing methane content at approximately 44% (Table 2).

Plate 25 pictorially shows that at negative pressures between 0.5 and 0.1 inches of water pressure, the pressures fluctuated and were influenced by external phenomena; and that at negative pressures above 0.1 inches of water pressure, the pressures were too small and erratic to measure accurately. Therefore, it was assumed that an effective radius of influence that could be used to space the wells and determine the total gas production would be where the head of negative 0.1 inches of water pressure is as determined by formula 1 on Plate 23 and formula 3 on this page. Using formula 3, with the withdrawal rate (Q) equal to 50 cfm and the head (h) equal to negative 0.1 inches of water pressure, the radius of influence is approximately 130 feet.

If the wells are spaced at the apex's of equalateral triangles whose distance from the apex to the intersection of the perpendicular bisectors is 130 feet, the distance between the wells is approximately 225 feet. Using this spacing, a calculated withdrawal rate per acre is 99.2 cfm. With an effective surface area of 150 acres of landfill, and this well configuration, the total site could produce 10.3 mmcfd at 44% methane gas. Refer to Part F, "Calculations," of the Appendix for calculations.

Accuracy

The accuracy of the data depended upon our ability to maintain a constant gas withdrawal rate, measure the actual pressures within the landfill, obtain gas samples and analyze the samples. The positive displacement-type pump was chosen so that minor pressure fluctuations in the landfill and atmosphere would be negated and the withdrawal rate would only depend on the speed of the pump. It was difficult to keep the Volkswagon engine which drove the pump by belts at a constant speed. The horsepower required by the pump was negligible compared to the horsepower output of the engine so that the engine was essentially under no load. The engine had to be checked at least twice a day and the engine adjusted if the speed was not right.

The pressures in the landfill were measured by manometers through 1/4-inch tubing that were as long as 250 feet. Accurate and consistent results were obtained until water from the gas started getting into the tubing. The water had to be constantly forced out of the tubing with air pressure before the pressure readings could be taken. Pressure readings above negative 0.1 inches of water pressure were difficult to measure because the pressures were always changing, probably due to atmospheric and decomposition rate fluctuations, and the readings could not be duplicated exactly. For pressure readings from negative 0.1 inch to negative 0.5 inches of water pressure, the majority of the readings were steady but could not be duplicated after a couple of hours. For pressure readings below negative 0.5 inches of water pressure, the readings were consistent.

The gas sampling and analysis accuracy was very good. A bad sample was easily noticed by the presence of high air content, over 5%, and could be disregarded.

# IMPLEMENTATION, TESTING, AND OPERATION

## Design versus As-Built

Since there were many unknowns and variables associated with the project, the design incorporated flexibility and sizing sufficient to handle the maximum withdrawal rate of 200 cfm. Only minor changes had to be made from the original design.

## Construction

No major problems occured during construction. By using a 36-inch auger, the wells were easily drilled without any delays. It was difficult to keep the piping straight in the well since the well had to be backfilled by dropping 3" rock and clay into the well. But since the pipes did not have to be straight to withdraw gas, the procedure was satisfactory.

## Testing

As part of the project, Pacific Gas and Electric Co. analyzed the gas samples and they supplied syringes to take the samples. No problems occurred in taking the samples at positive pressure locations. Considerable care was necessary if a sample had to be taken at a negative pressure point.

There was some problem in receiving results in sufficient time to make corrections in the operations. This was no fault of the sampling or analysis. It took time to conduct the analyses, and when the gas composition was changing rapidly we could not keep up with it.

## Equipment Maintenance

The only high maintenance items were the Volkswagon engines. A spare engine was always kept on hand. A lower maintenance engine or electric motor, though more expensive, would have provided a more continuous and consistent operation.

When the engines were running on the landfill gas, the spark plugs fouled faster than on gasoline and the carburator would ice up during the night. A shroud had to be placed over the engine to keep the carburator warm enough so that icing would not occur.

Our experience shows that a less refined combustion engine or electrical motor would have been better for driving the pumps.

## ANALYTICAL PROCEDURES

The following were the standard sampling procedures used.

### Sampling

The pH was determined by taking a beaker of water from the demister on the positive pressure side of the pump. The pH was measured with an electronic direct reading instrument, 0.2 graduations, 0.05 accuracy. A CENCO laboratory pH meter, Catalog No. 21660, was used.

The temperature, measured in degrees Fahrenheit, was measured from a thermometer located in the well casing immediately above the ground. The ambient temperature was measured in a location that was away from the pump station.

The pressure within the landfill was measured via a 1/4-inch plastic tube which was run from each pressure point in the landfill to a central monitoring board located in an enclosed metal building. Each tube had a separate on/off valve. All the valves were connected to a slant tube manometer, 0.20-0-3 inches: water, 0.01 increments, and slant tube manometer which read up to 72 inches, 0.1 inch increments, water. Each pressure point was measured by turning on the appropriate valve and reading the manometer. Dwyer manometers were used, Model Nos. 2C9 and 1211-72.

To determine the methane gas content of the landfill gas, a gas sample was taken from the valve and sampling tube on the positive pressure side of the pump. The sample was taken with a syringe by inserting the needle into the tube and allowing the gas pressure to force gas into the syringe. The syringe was purged at least once. A "PLASTIPAK" disposal syringe order No. 3663, 50 cc capacity, LUER-LOK tip, was used.

### Monitoring

All the pressure points in the landfill were lead onto a monitoring board via 1/4-inch plastic tubing and each point had a separate on/off valve. The pressures could be read on a manometer by consecutively opening and closing each valve. The system worked fine until water from the gas started building up in the tubing. Additional time had to be spent clearing all the lines with air pressure before the pressures could be read. There were two manometers, a 72-inch manometer and a 3-inch manometer. Each manometer was connected to the monitoring board by a valve.

Analyses

For Phase 1, the original procedure used to determine the optimum methane gas production rate was to start out at a high withdrawal rate and steadily reduce the rate twice a week until an acceptable methane content was reached. Once that rate was established, the landfill would be pumped for 30 days to confirm the initial methane content.

As Plate 14 depicts, the initial withdrawal rate of 200 cfm was too high and had to be reduced to eventually 50 cfm before a consistent methane content was reached. This meant that the initial procedure to establish the optimum production rate was too short to depict the capacity of the landfill. A period of a week seems more advisable for the length of time at each pumping rate. At least twice a week the following should be recorded: temperature (ambient and gas), atmospheric pressure and pressure in all monitoring wells and production wells.

From the second interim annual report of the Sonoma County Refuse Tests Cells, Solid Waste Disposal Demonstration Grant, Project G06-EC-00351, prepared by EMCON Associates, it was shown that the leachate pH was contaminated by soluable gases, especially carbon dioxide, and the pH remained around 5. Therefore, the pH should be sampled once from each production well. During the pumping, a complete analysis of the gas should be made twice a week.

For Phase 3, the procedure used to determine the effect of moisture content was to take the optimum rate established in Phase 1 and continually pump the wells 1A and 1B while adding water to only the refuse surrounding well 1A. The temperature (ambient and gas), atmospheric pressure, and the pressure in all monitoring wells and production wells were recorded, and a complete analysis of the gas was made twice a week. After running the pump station for 2 weeks, sufficient water was added to the refuse around well 1A to raise the moisture of the refuse by 10%. If the project had not stopped at this point, for every 2 weeks 10% moisture would have been added until 60% moisture was reached.

Analyses of the gases drawn from wells at the landfill were made both on-site and in the laboratory. The on-site analyses covered the identification and quantification of sulfur compounds; the laboratory analyses include the hydrocarbons and fixed gases.

The on-site analyses for sulfur compounds were performed by the PG& E Department of Engineering Research personnel using an Austin Gas Titrator. This instrument has the capacity of analyzing for sulfur compounds in the following classifications: hydrogen sulfide, mercaptans, sulfides, and disulfides. This instrument does not have the capability of identifying individual sulfur compounds such as methyl or ethyl mercaptan, but through selective absorption techniques, identifies mercaptans as a group.

The laboratory analyses were accomplished on a Beckman GC-4 gas chromatograph using a three column configuration and a thermal conductivity detector operating at 80 degrees centigrade column temperature. Oxygen-argon, nitrogen, carbon monoxide, and hydrogen were separated and determined quantitatively using an 8-foot by 3/16-inch molecular sieve 5A column. A 16-foot by 3/16-inch Porapak Q Column was used to separate and quantitatively determine methane, carbon dioxide, ethane, ethylene and water vapor. Hydrogen, if present in relatively low concentrations, can be determined quantitatively with this column. Hydrogen sulfide, if present in quantities greater than 100 parts per million, can be determined using a 30-foot by 3/16-inch silicon 200/500 on Chromosorb P Column.

PLATES AND PICTURES

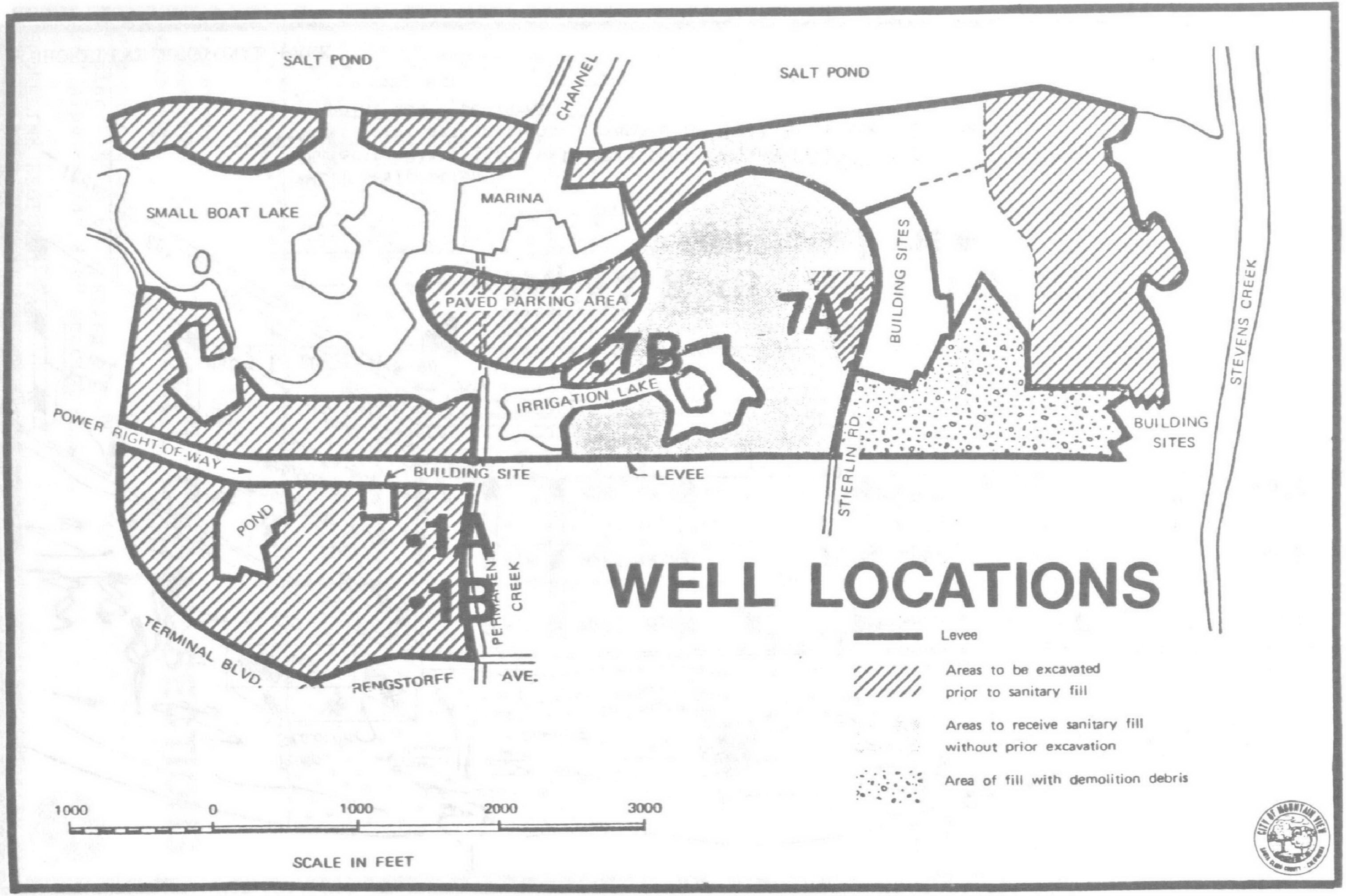
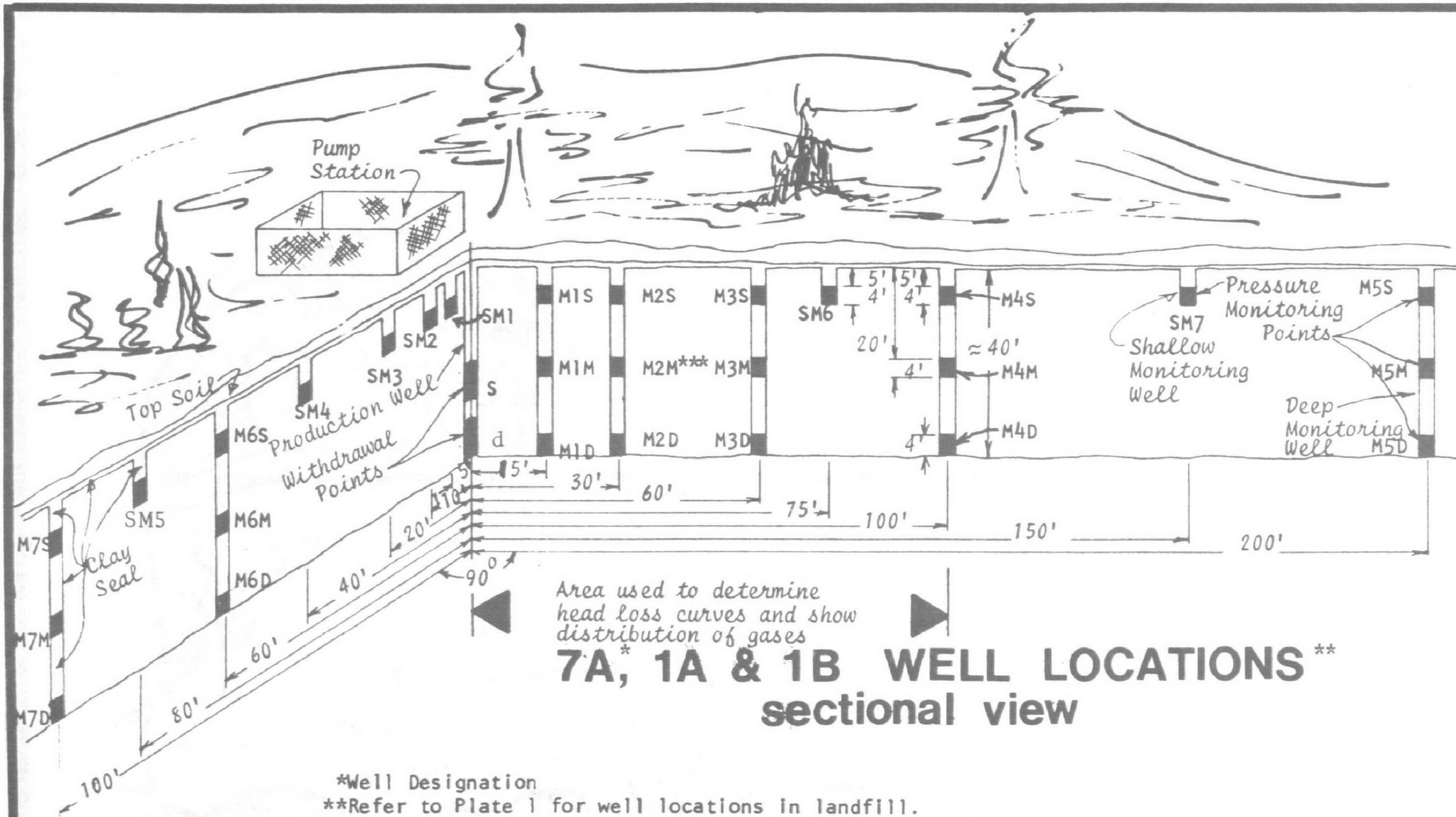

SALT POND
SALT POND
CHANNEL
MARINA
SMALL BOAT LAKE
PAVED PARKING AREA
7A
7B
BUILDING SITES
IRRIGATION LAKE
POWER RIGHT-OF-WAY
BUILDING SITE
LEVEE
STIERLIN RD.
BUILDING SITES
STEVENS CREEK
POND
1A
1B
PERMANENTE CREEK
TERMINAL BLVD.
RENGSTORFF AVE.
WELL LOCATIONS
Levee
Areas to be excavated prior to sanitary fill
Areas to receive sanitary fill without prior excavation
Area of fill with demolition debris
1000
0
1000
2000
3000
SCALE IN FEET

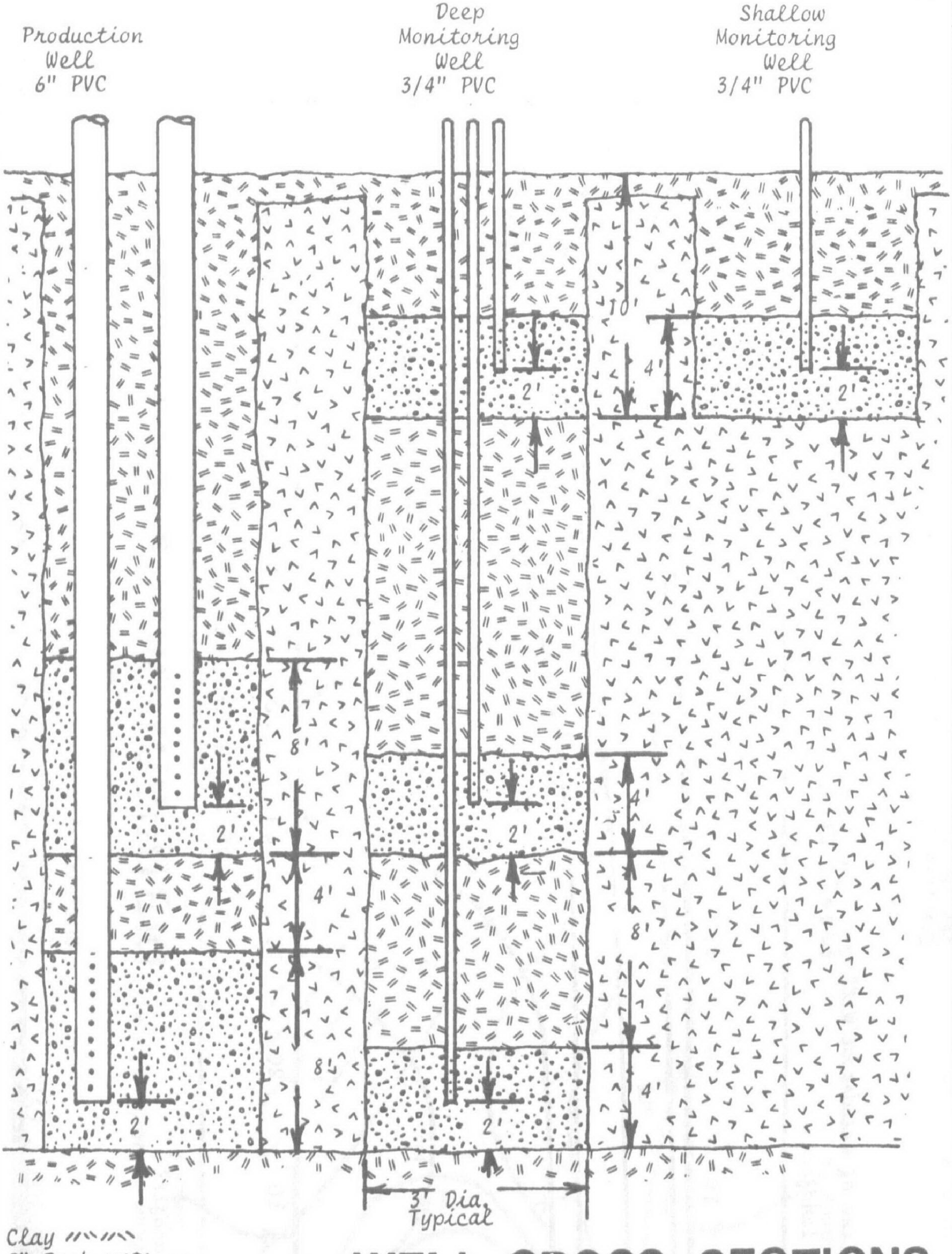
PLATE 1




# 7A,* 1A & 1B WELL LOCATIONS**
## sectional view

*Well Designation
**Refer to Plate 1 for well locations in landfill.
***Well point designations. Example for well 7A, asterisked monitoring point would be 7A-M2M.

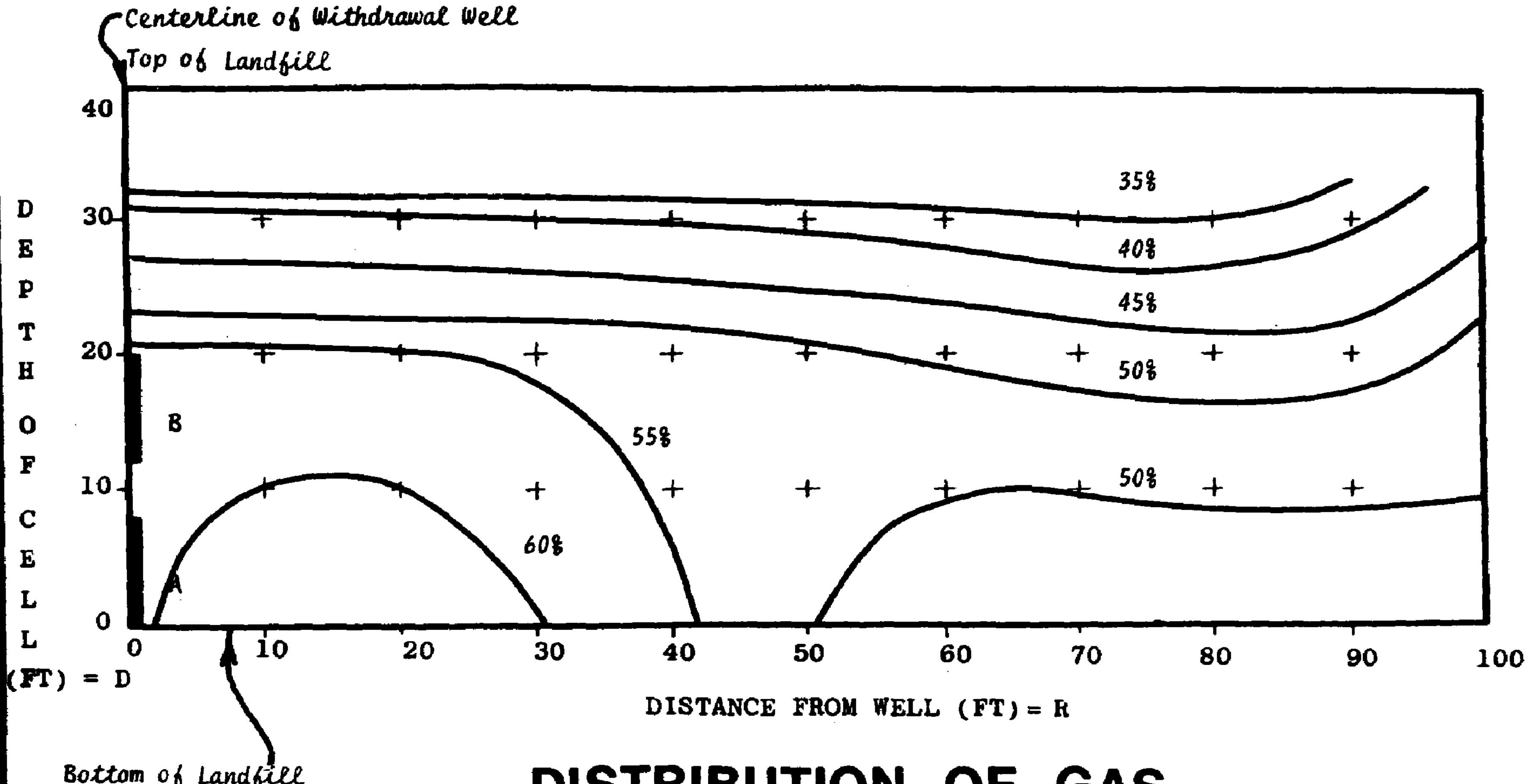
SHORELINE REGIONAL PARK




# WELL CROSS SECTIONS

Hole size & spacing
6" pipe - ½" @ 6" spacing
3/4" pipe - 1/4" @ 6" spacing

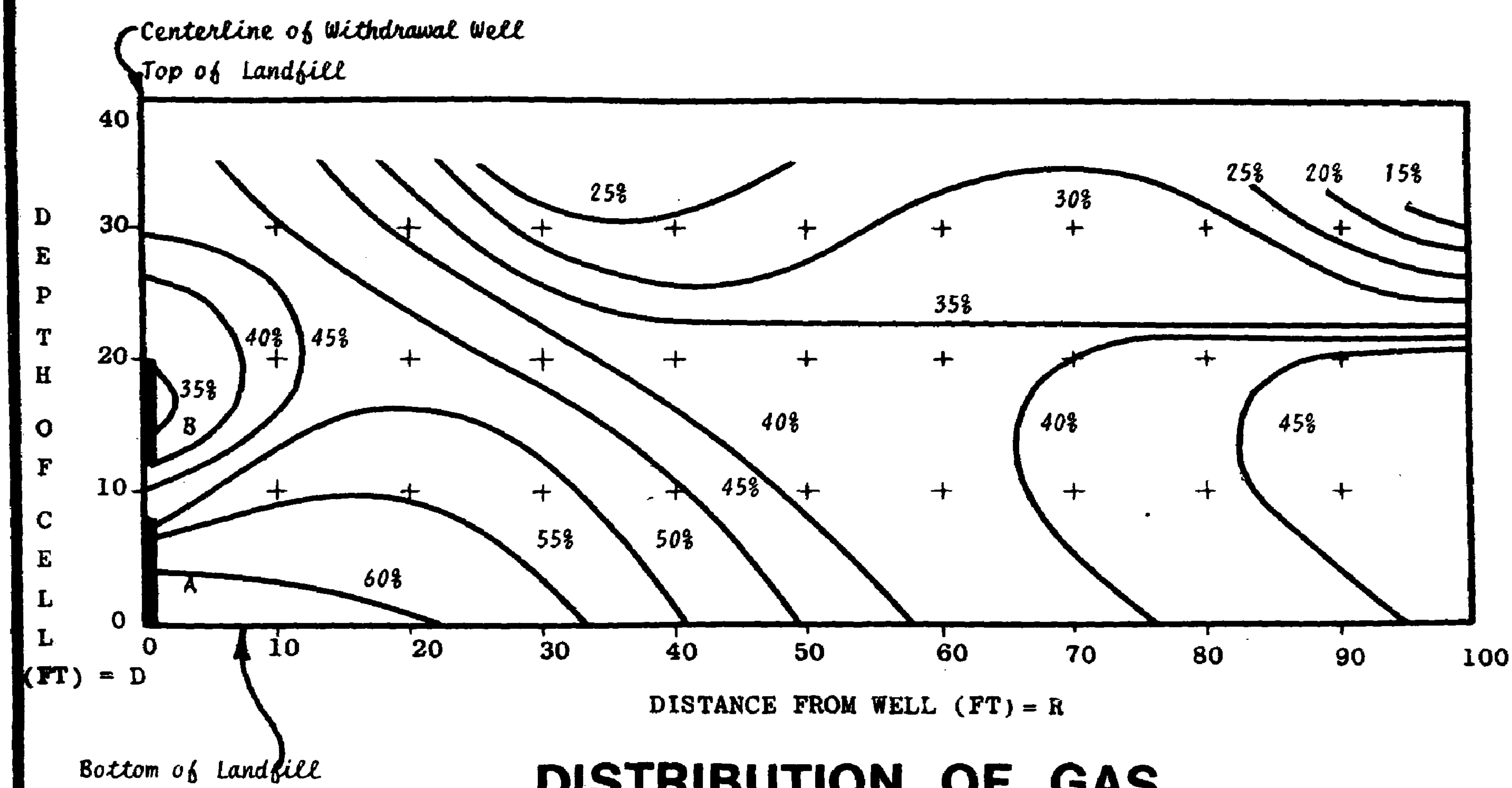
SHORELINE REGIONAL PARK




# DISTRIBUTION OF GAS

METHANE GAS

*Contours show concentration of methane gas prior to short-term pumping.*



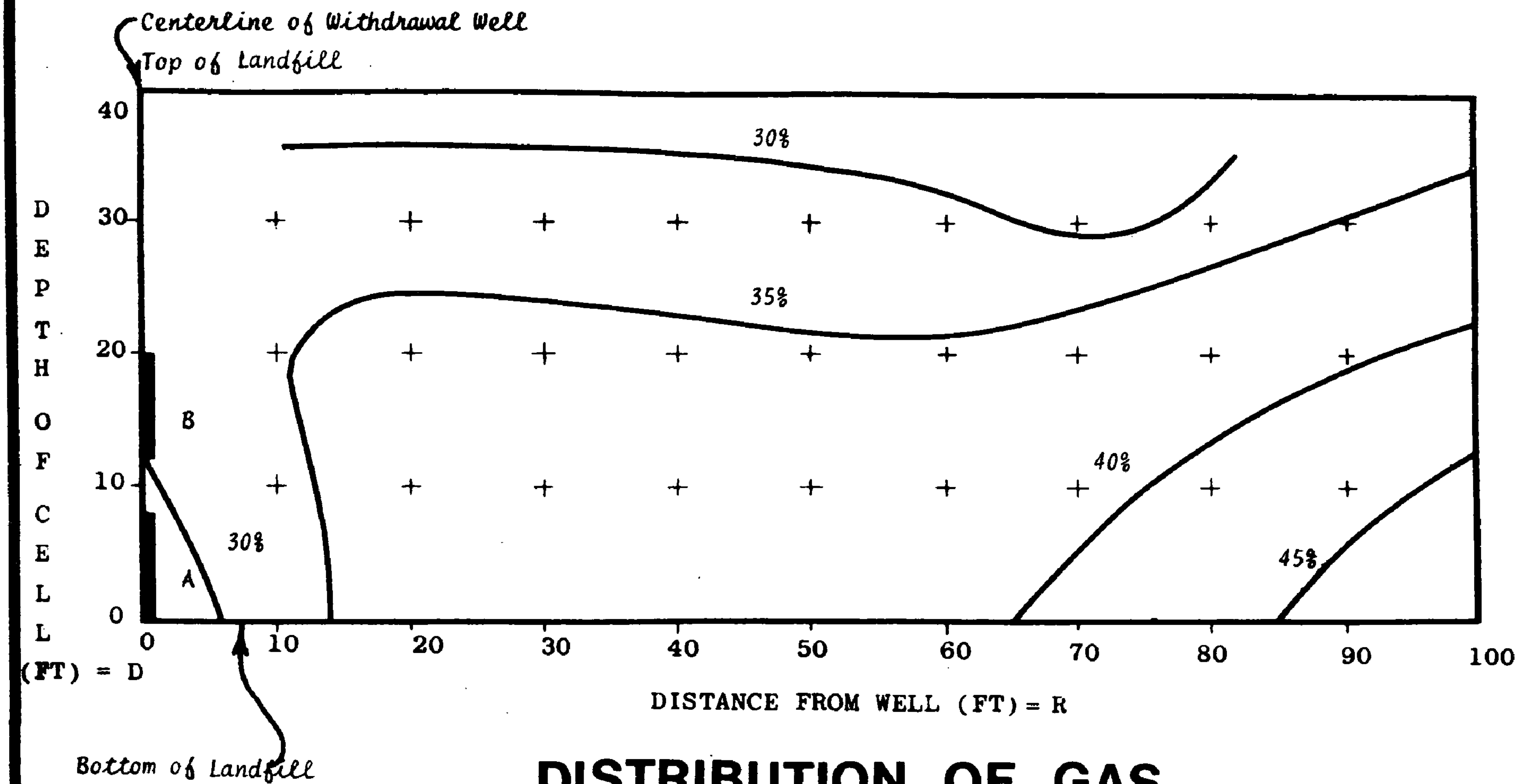

# DISTRIBUTION OF GAS

METHANE GAS

Contours show concentration of methane gas after the short-term pumping.

SHORELINE REGIONAL PARK

PLATE 5



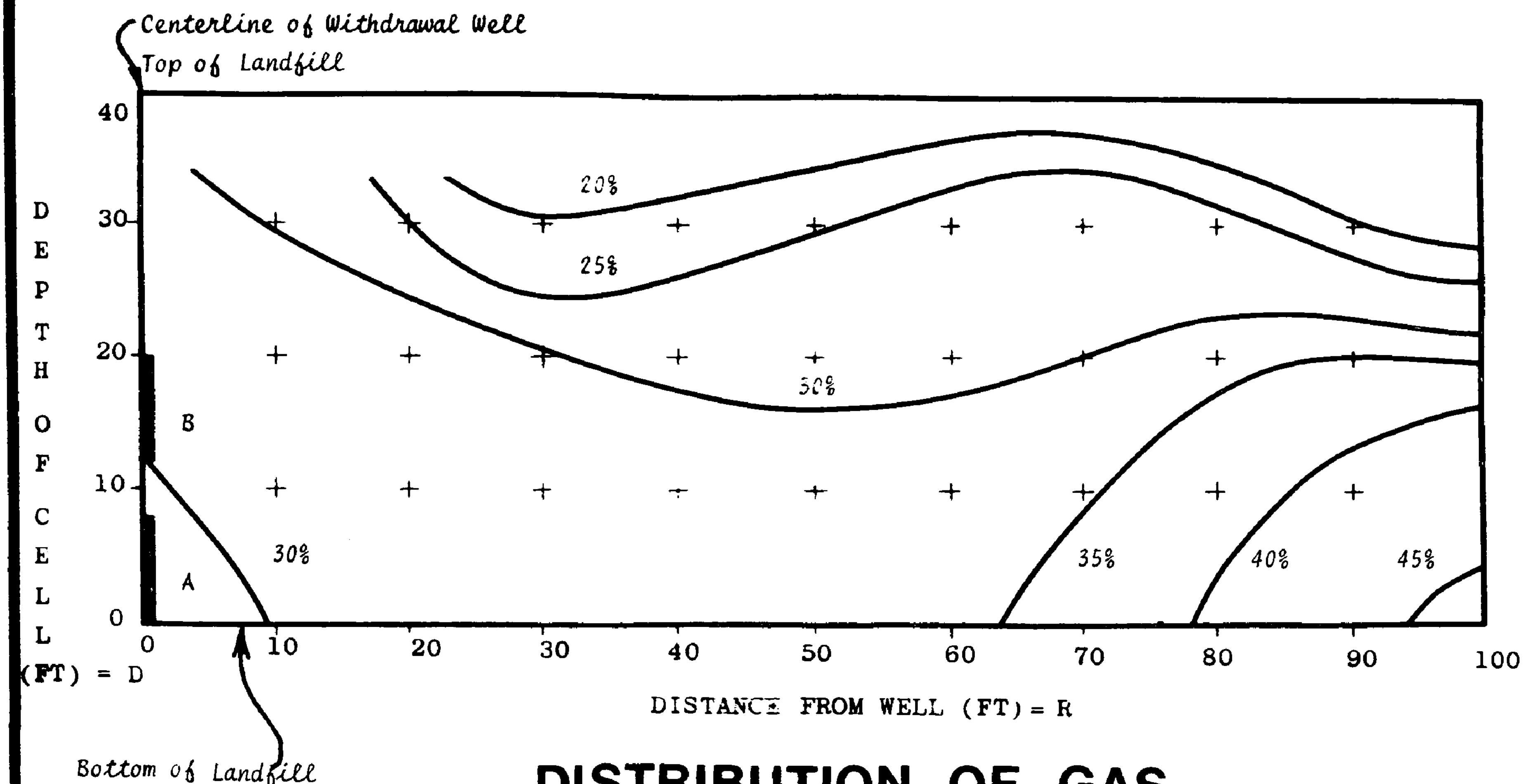

# DISTRIBUTION OF GAS

CARBON DIOXIDE GAS

*Contours show concentrations of carbon dioxide prior to short-term pumping.*

SHORELINE REGIONAL PARK

PLATE 6

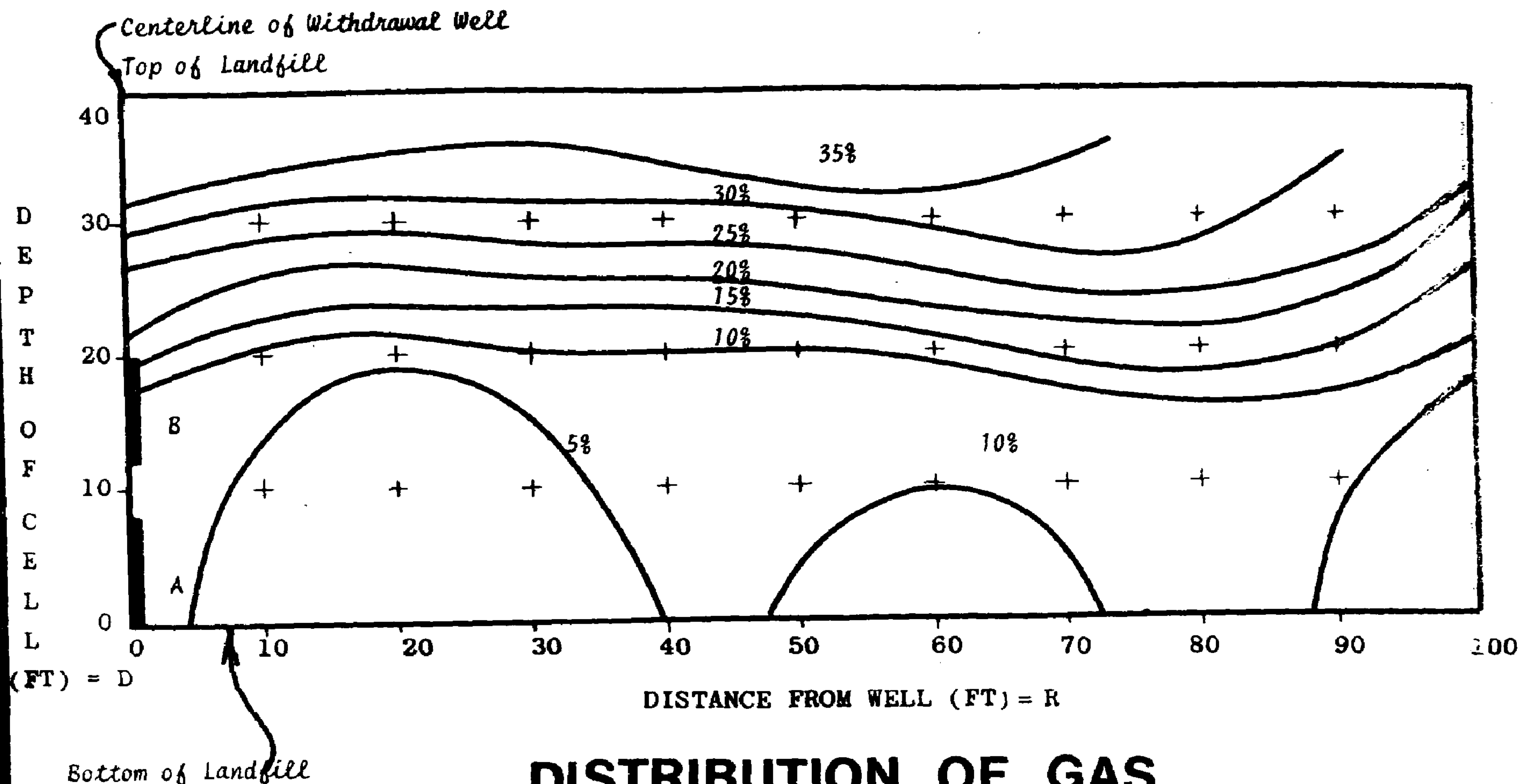



# DISTRIBUTION OF GAS

CARBON DIOXIDE GAS

Contours show concentration of carbon dioxide gas after short-term pumping.

SHORELINE REGIONAL PARK



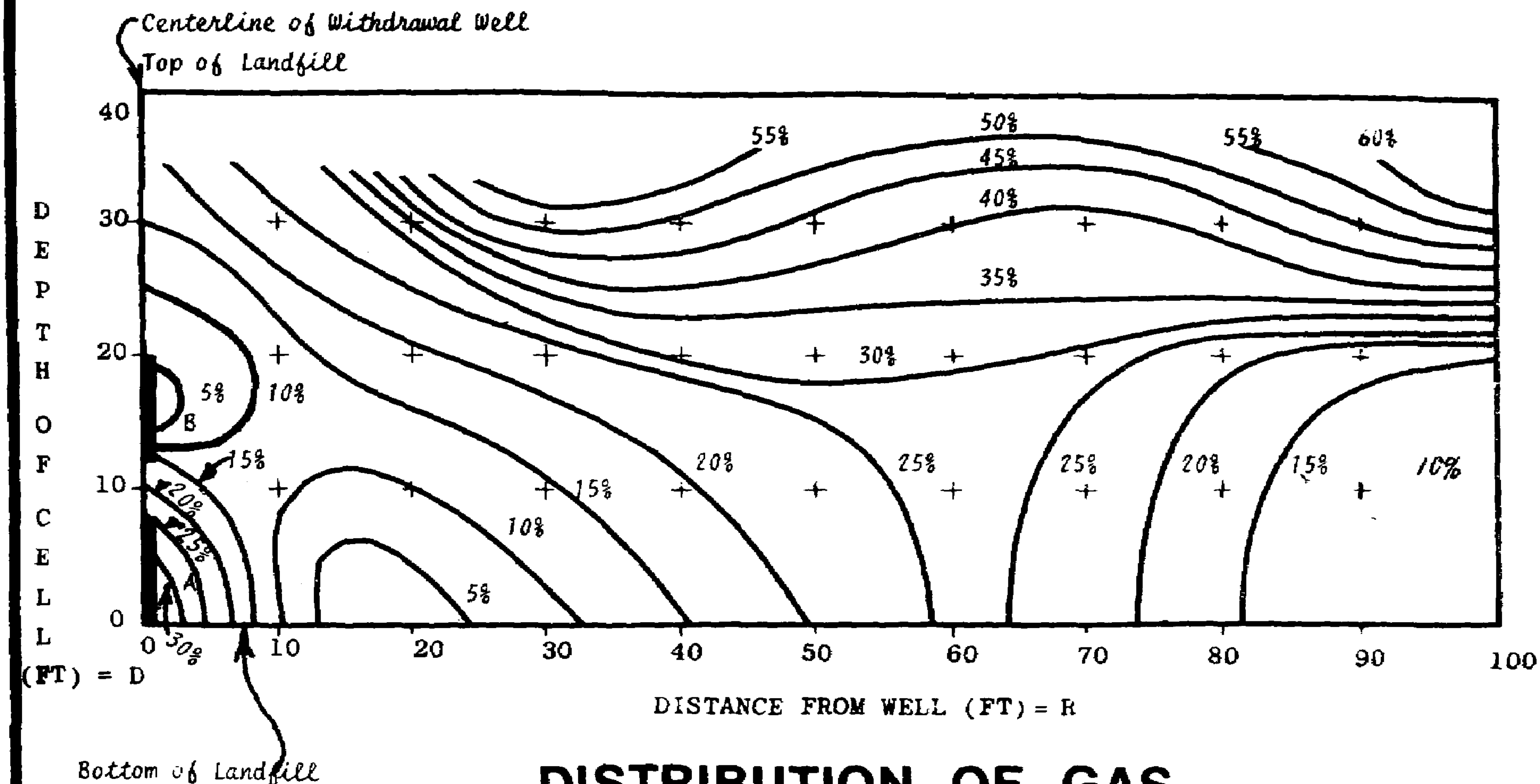

# DISTRIBUTION OF GAS

NITROGEN GAS

*Contours show concentration of nitrogen gas prior to short-term pumping.*

SHORELINE REGIONAL PARK

PLATE 8



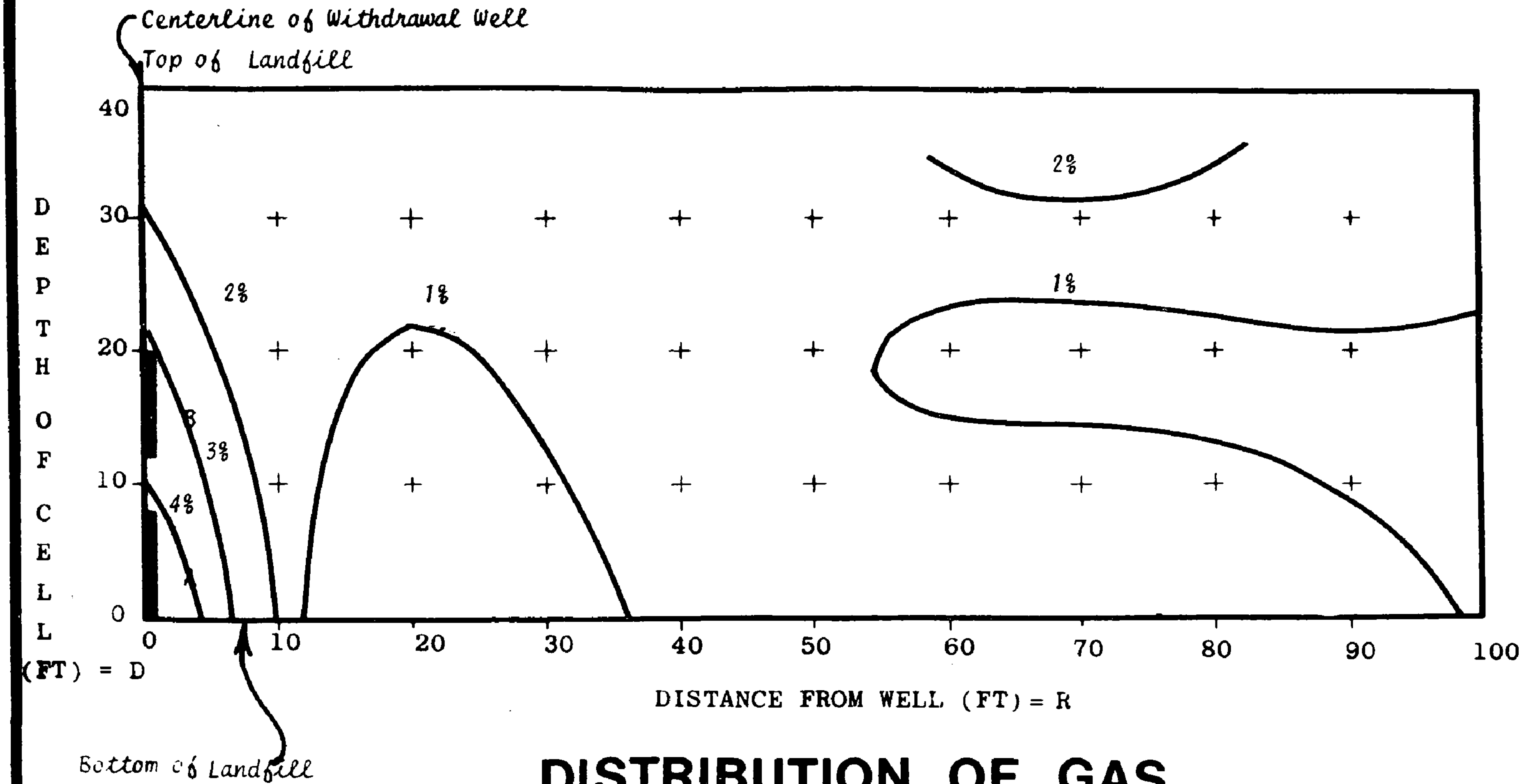

# DISTRIBUTION OF GAS

NITROGEN GAS

*Contours show concentration of nitrogen gas after short-term pumping.*

SHORELINE REGIONAL PARK

PLATE 9

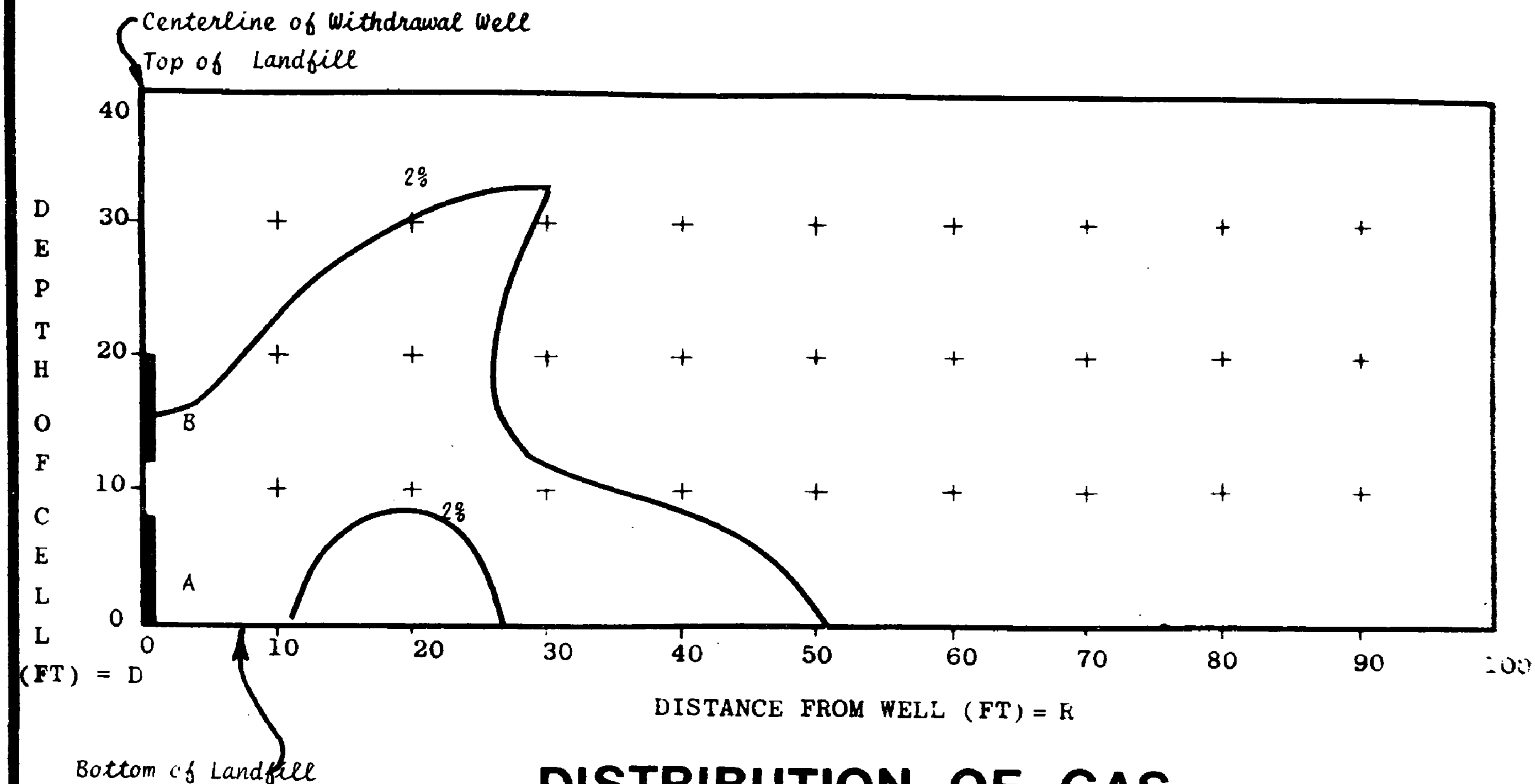



# DISTRIBUTION OF GAS

OXYGEN GAS

*Contours show concentration of oxygen gas prior to short-term pumping.*

SHORELINE REGIONAL PARK



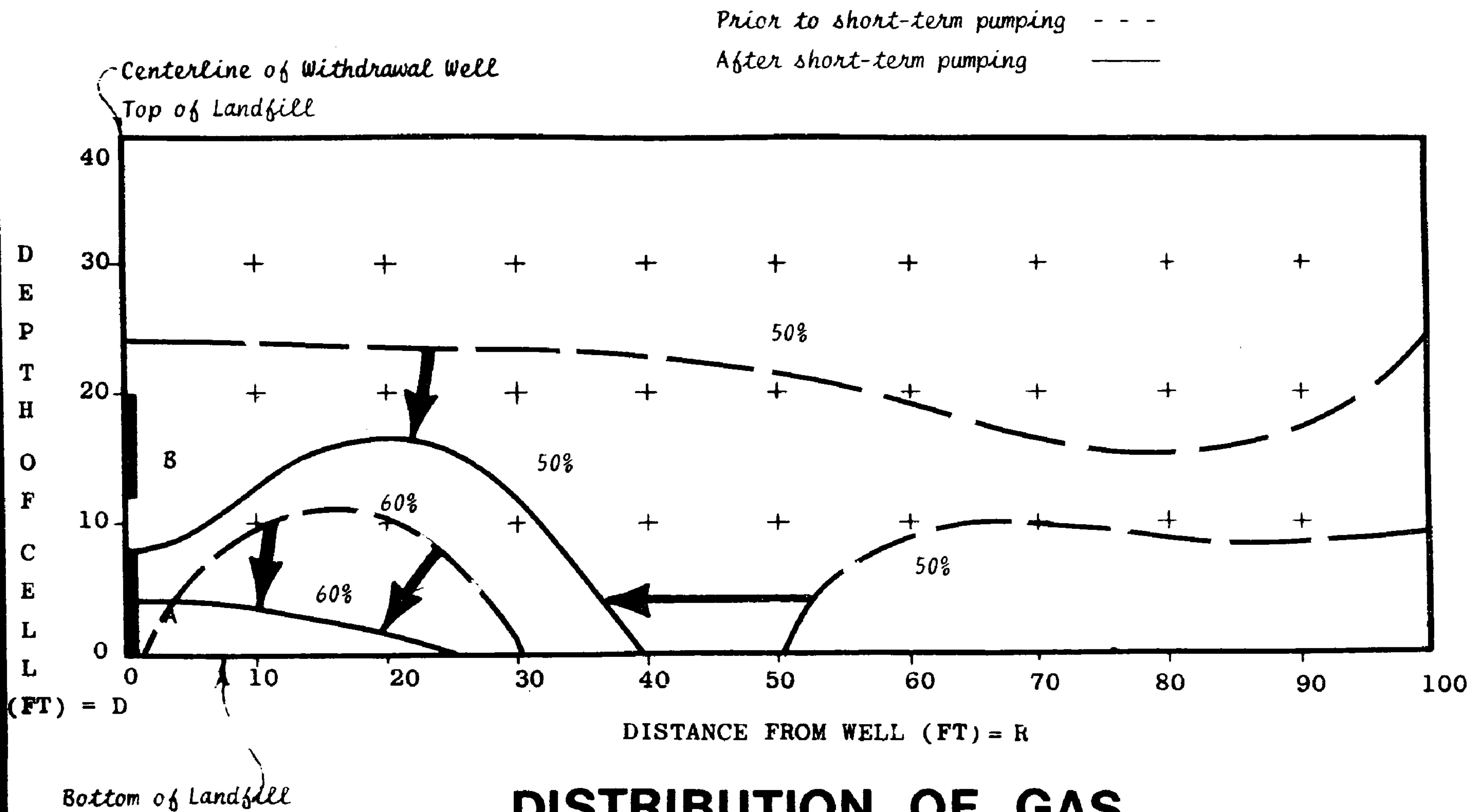

# DISTRIBUTION OF GAS

OXYGEN GAS

*Contours show concentration of oxygen gas after short-term pumping.*

SHORELINE REGIONAL PARK

PLATE 11

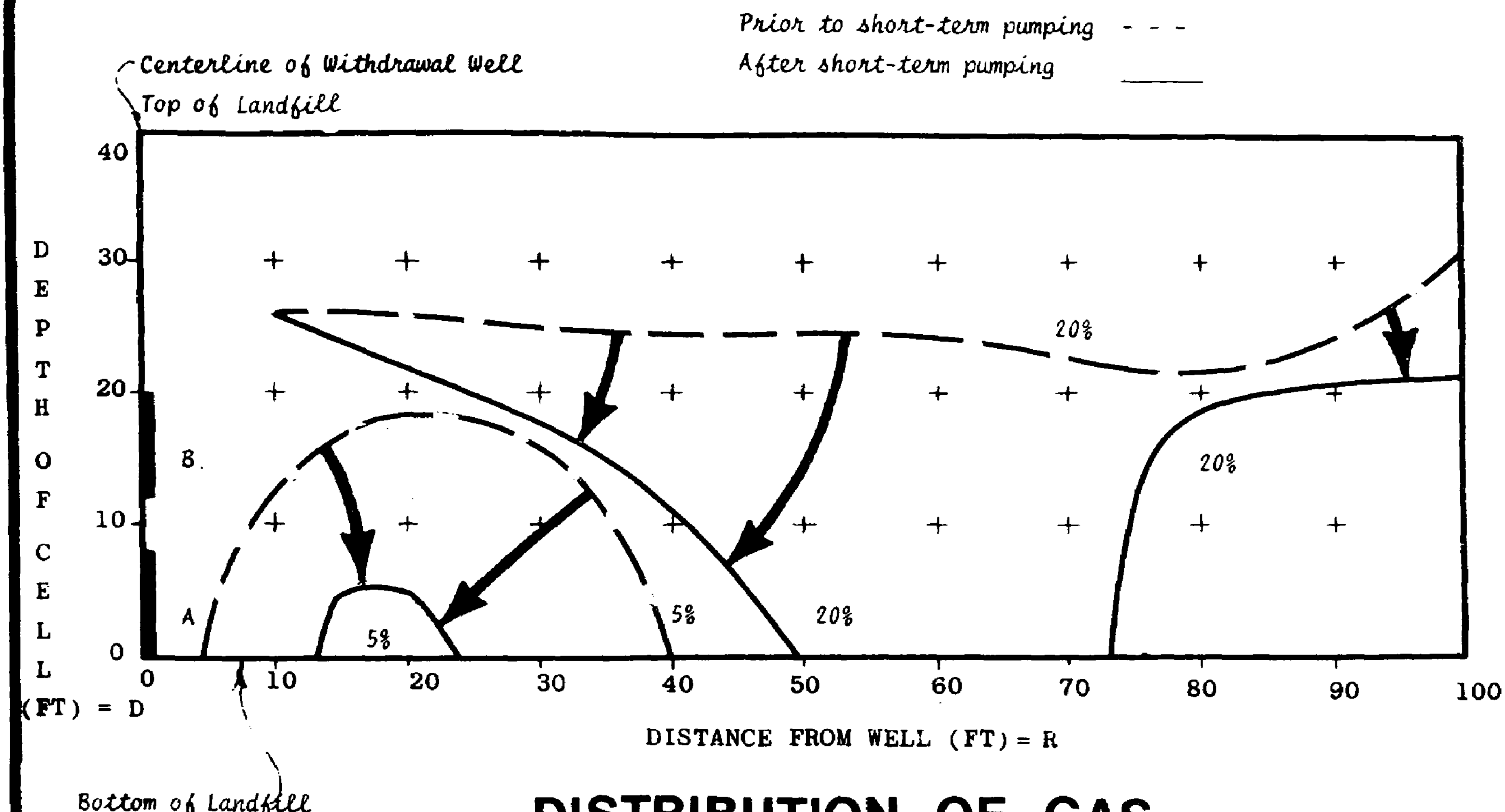



# DISTRIBUTION OF GAS

METHANE GAS

*Graph shows movement of gas as a result of short-term pumping.*

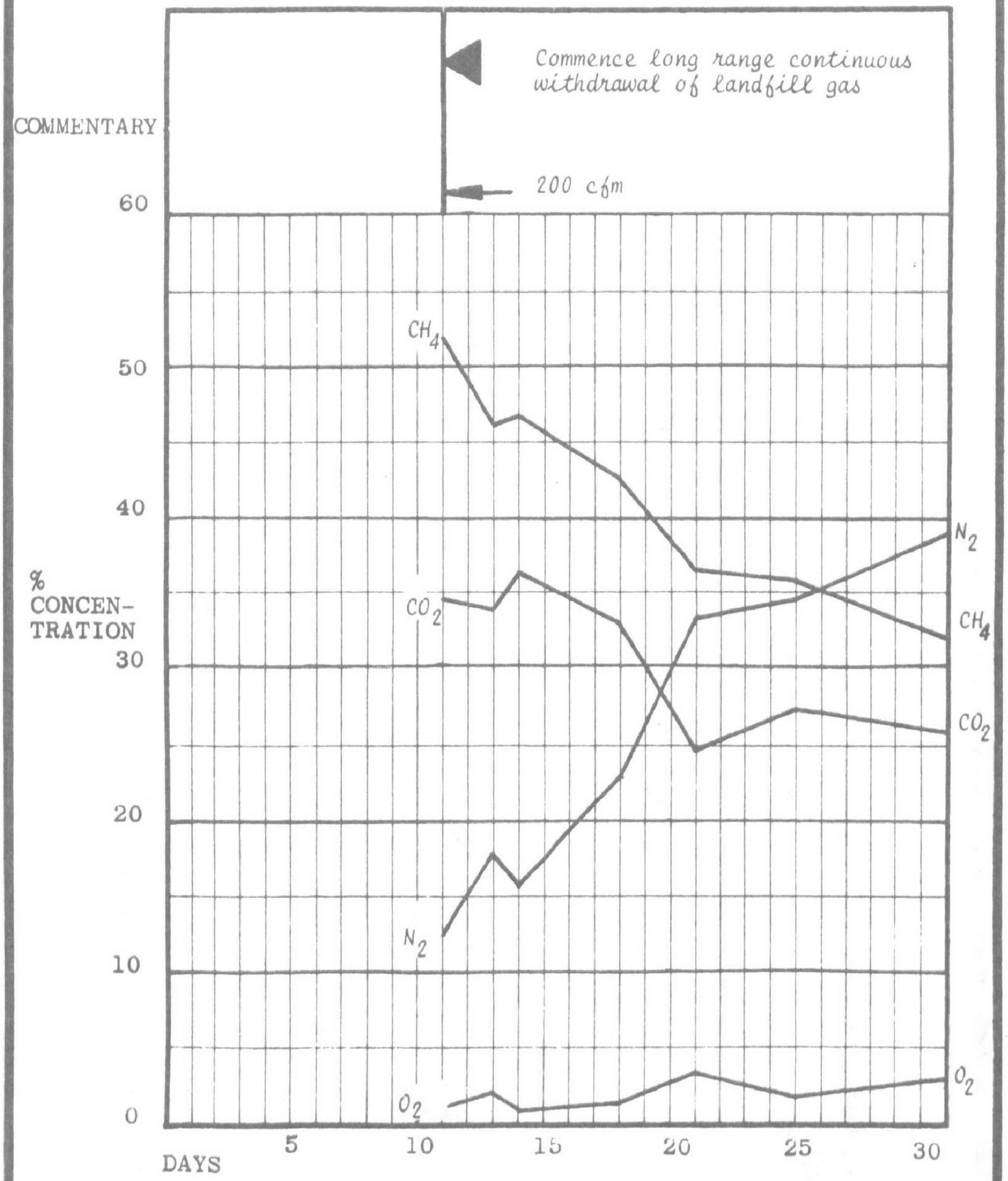
SHORELINE REGIONAL PARK




# DISTRIBUTION OF GAS

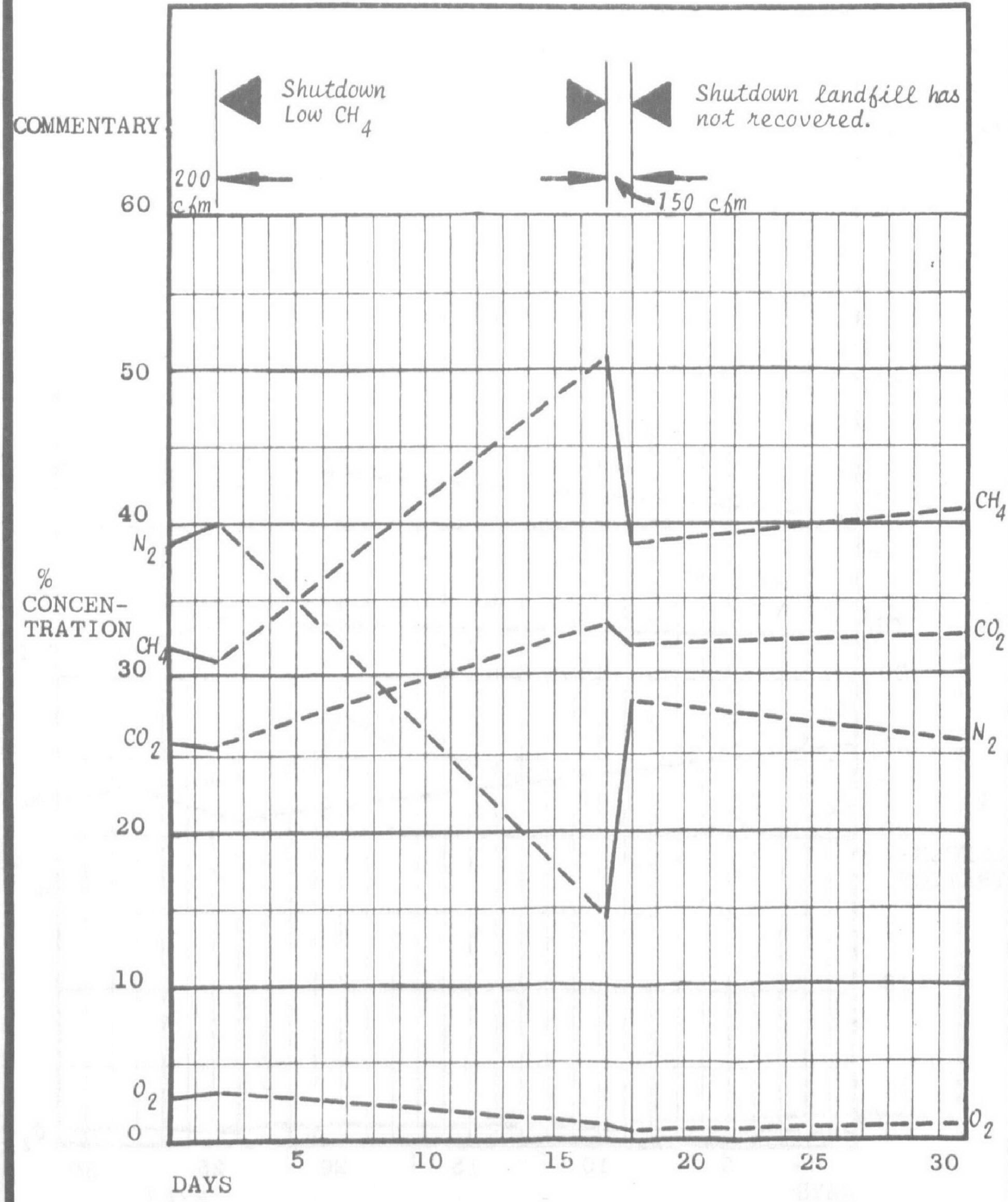
NITROGEN GAS

Graph shows movement of gas as a result of short-term pumping.




MONTH FEBRUARY 1975

# LONG RANGE CONTINUOUS GAS WITHDRAWAL CHRONOLOGY

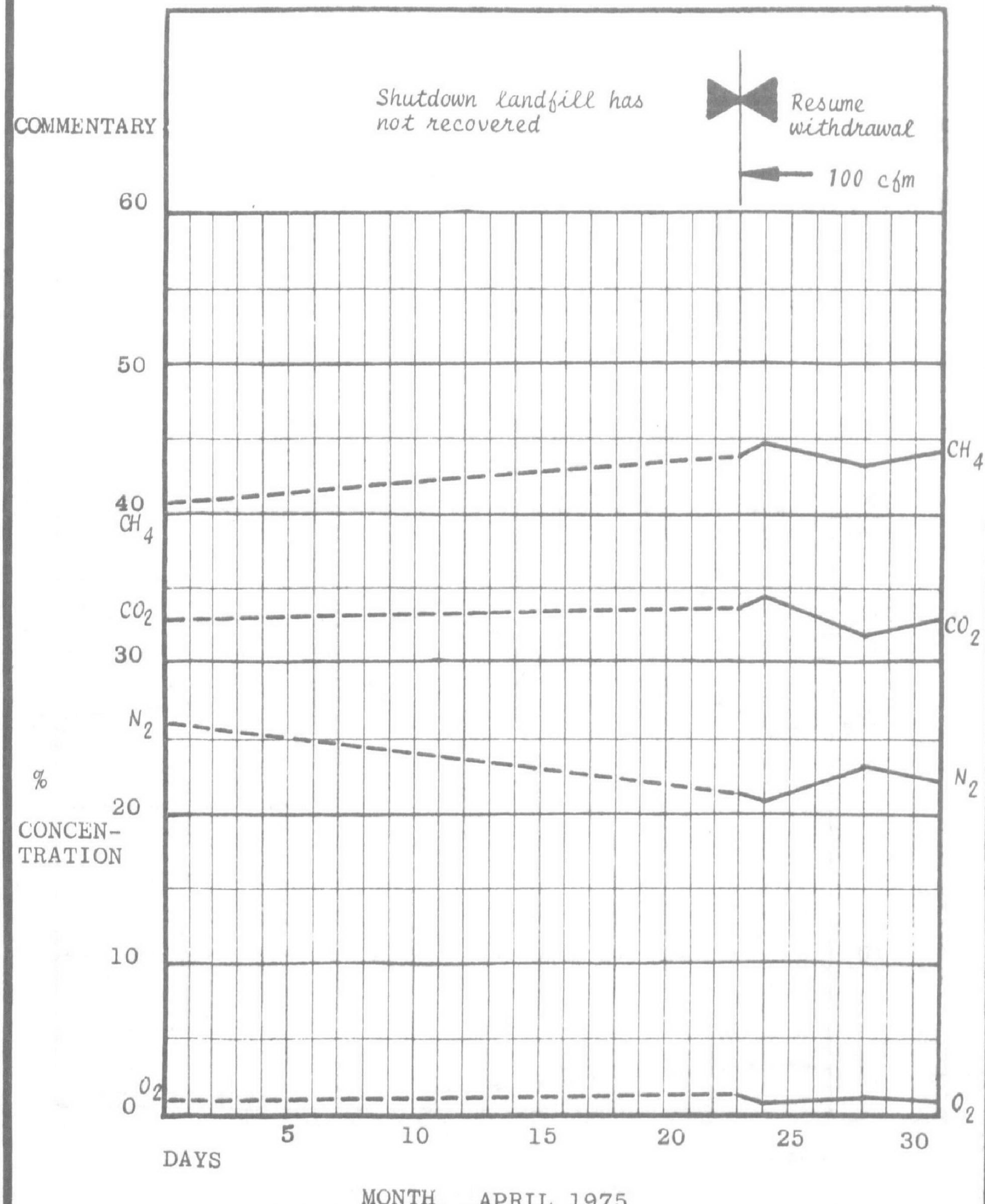



MONTH MARCH 1975

# LONG RANGE CONTINUOUS GAS WITHDRAWAL CHRONOLOGY

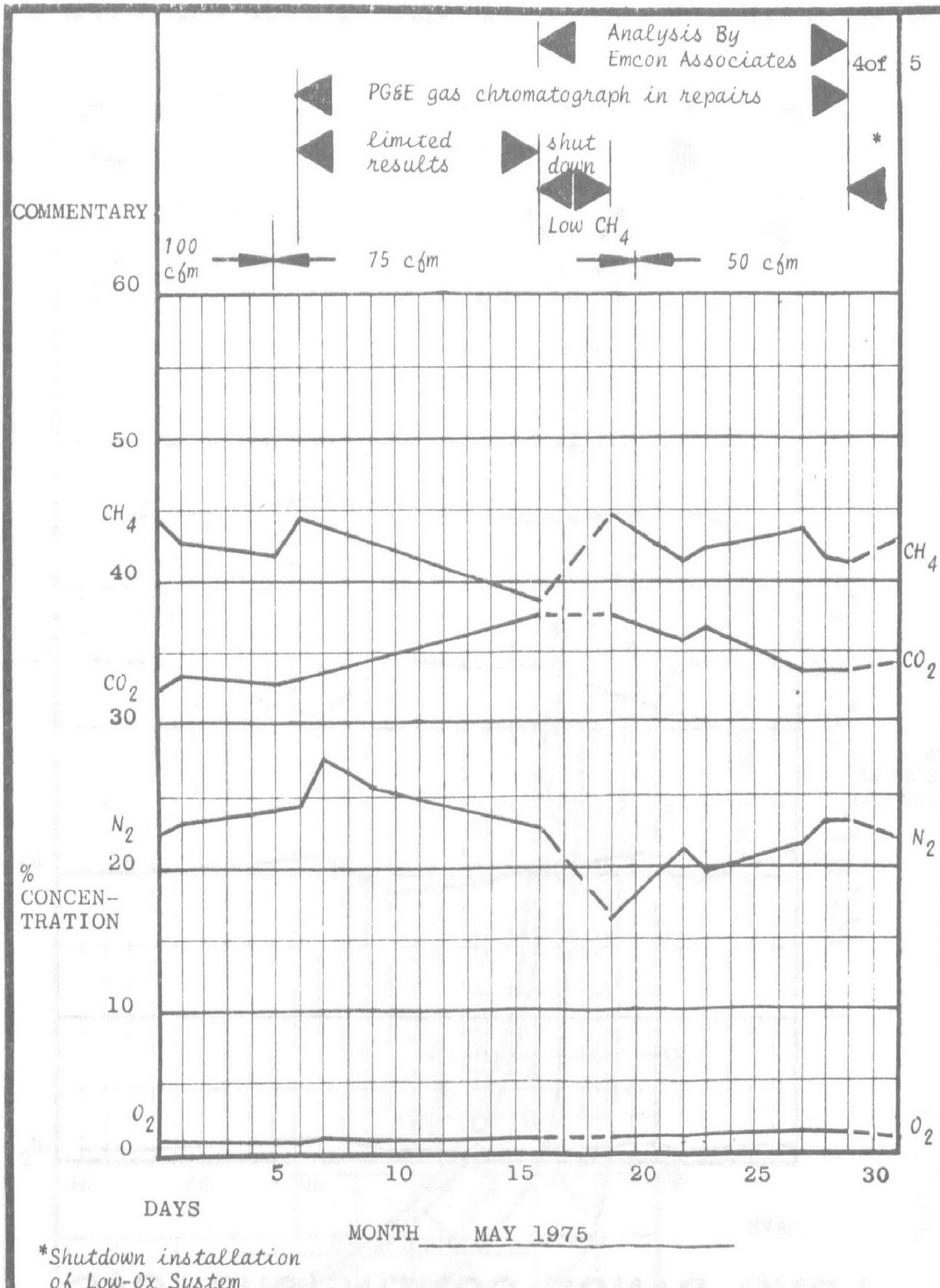


PLATE 14




MONTH APRIL 1975

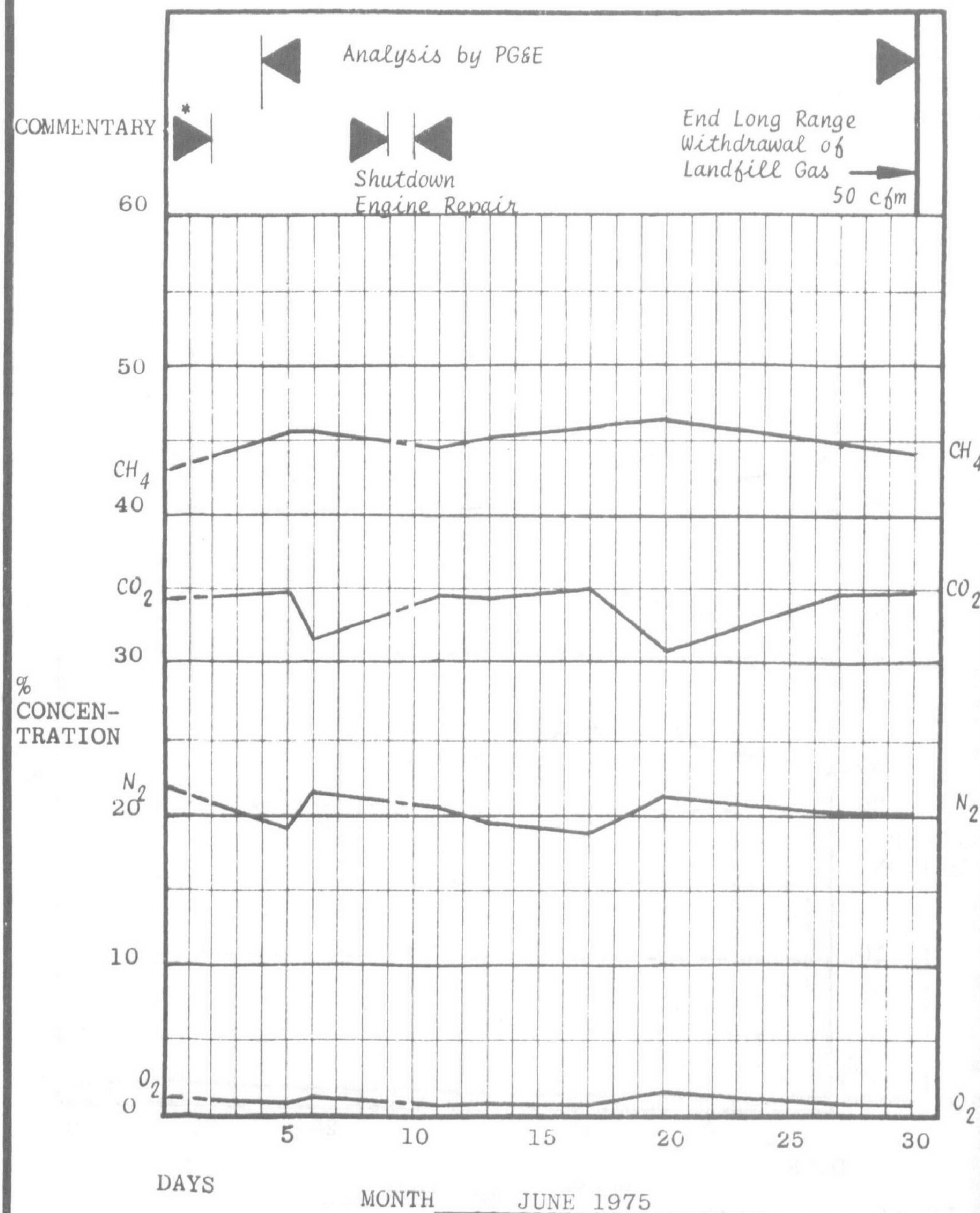
# LONG RANGE CONTINUOUS GAS WITHDRAWAL CHRONOLOGY




# LONG RANGE CONTINUOUS GAS WITHDRAWAL CHRONOLOGY



PLATE 14




MONTH JUNE 1975

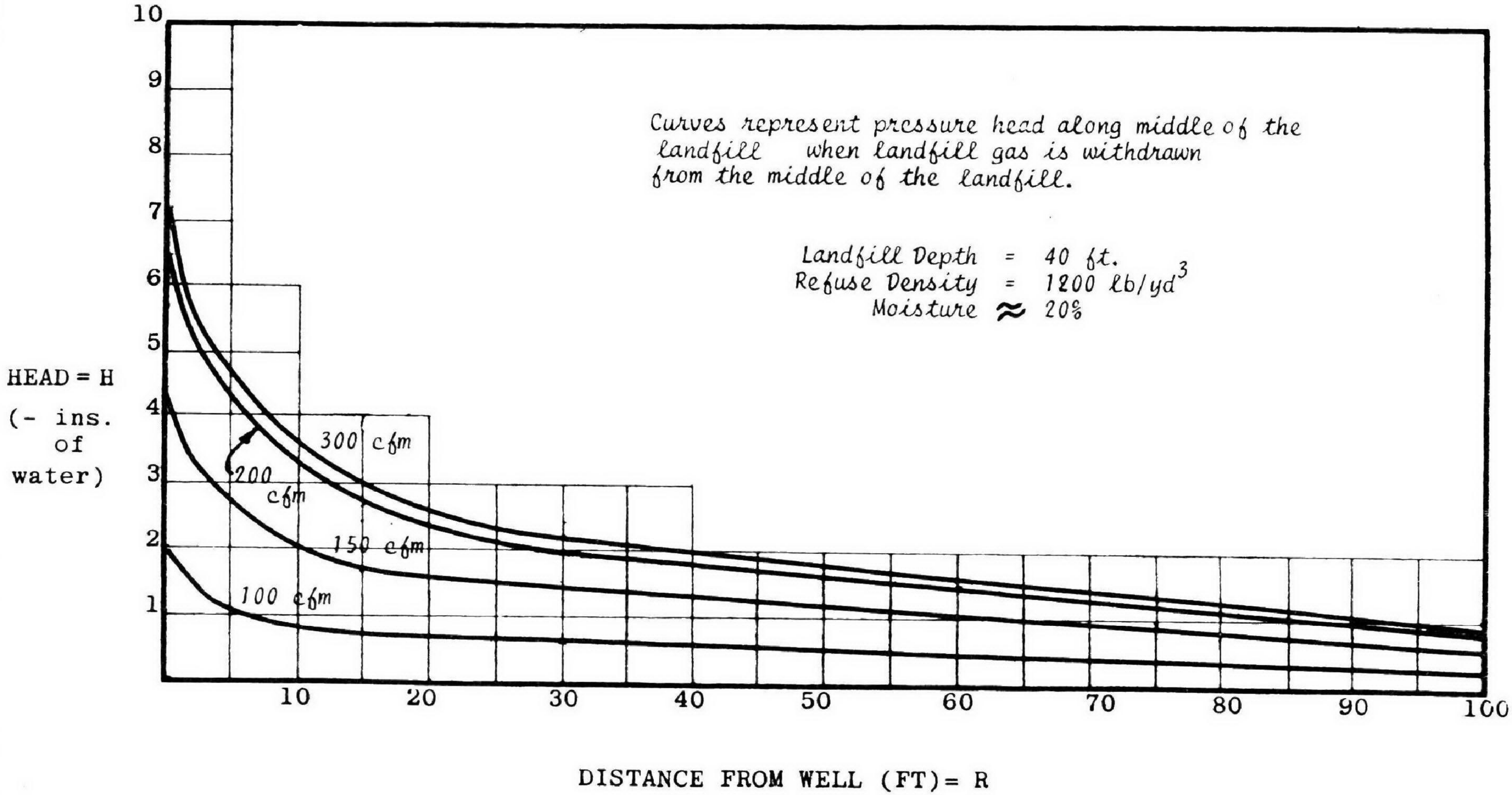
# LONG RANGE CONTINUOUS GAS WITHDRAWAL CHRONOLOGY

*Shutdown Installation of Low-Ox System

SHORELINE REGIONAL PARK



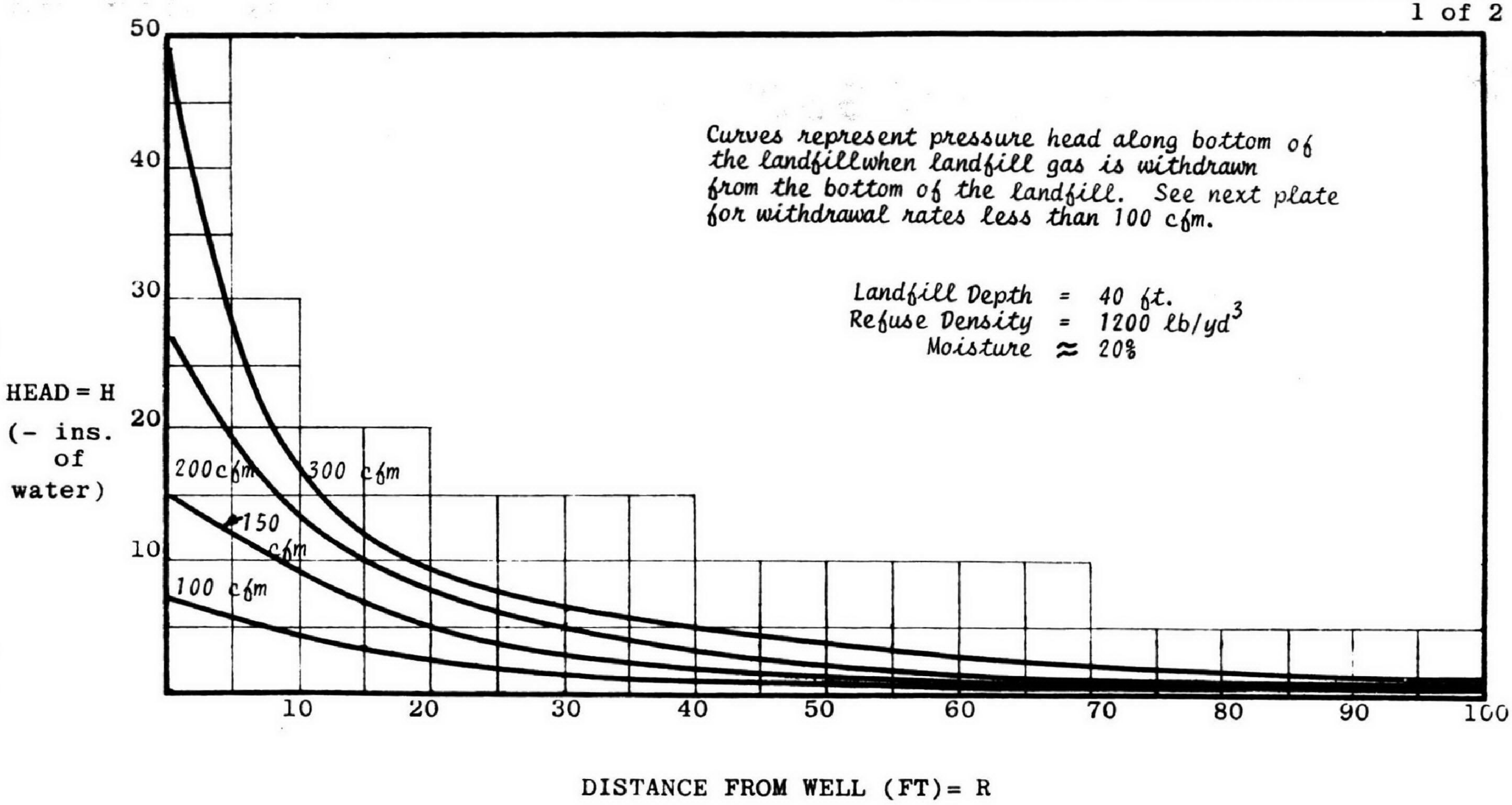
PLATE 14



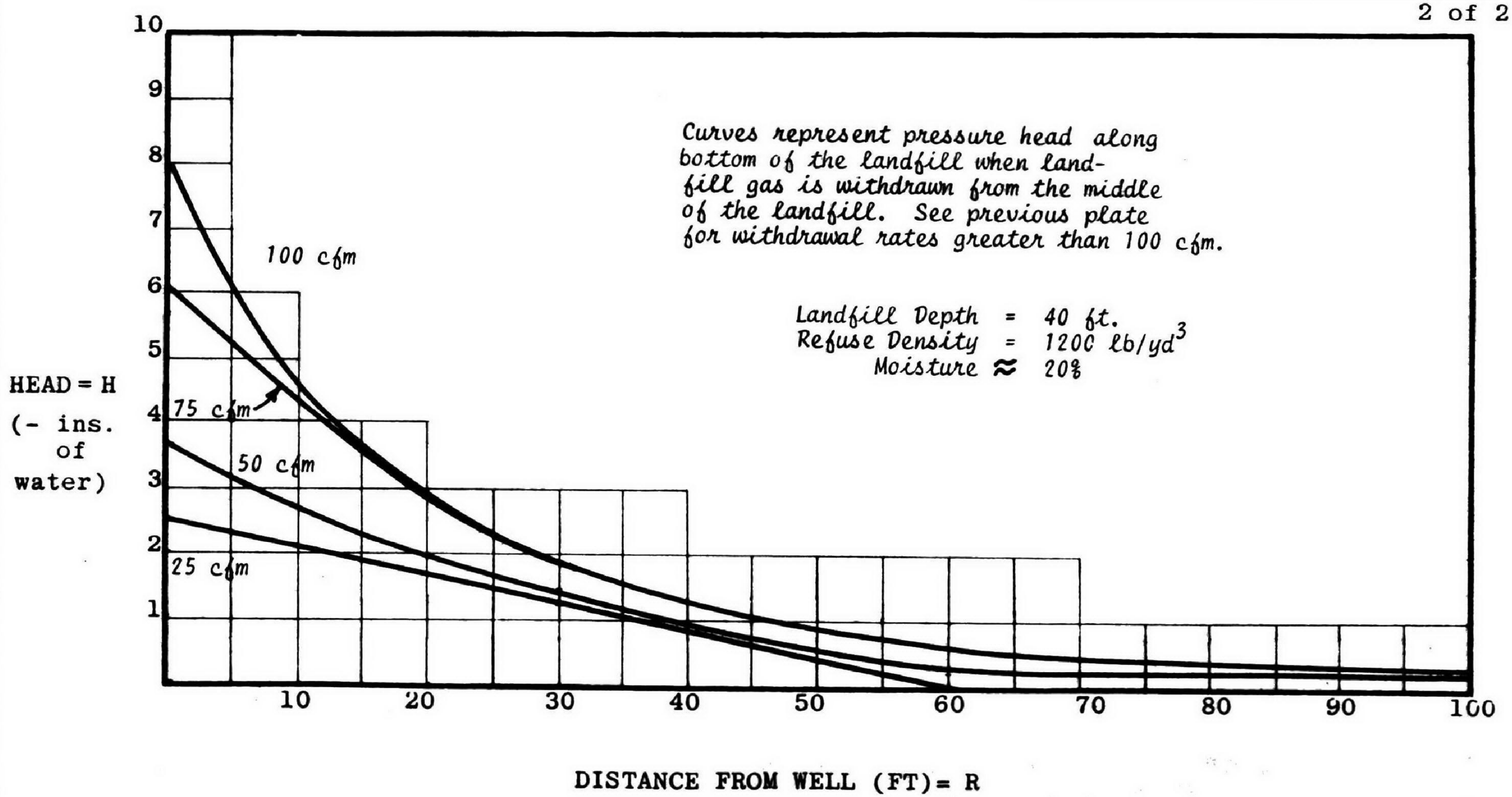

# HEAD LOSS CURVES

SHORELINE REGIONAL PARK

PLATE 15

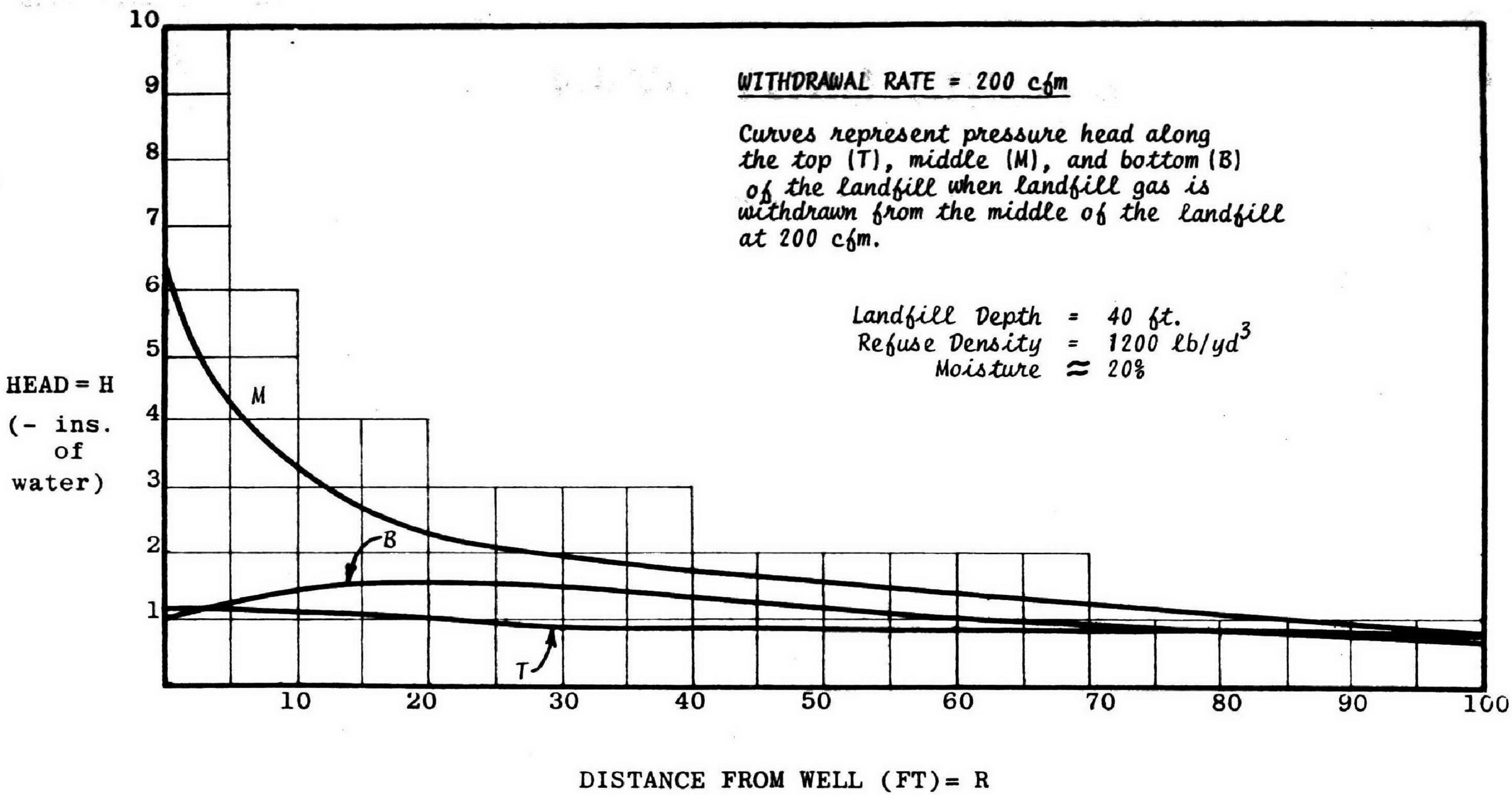



# HEAD LOSS CURVES




# HEAD LOSS CURVES

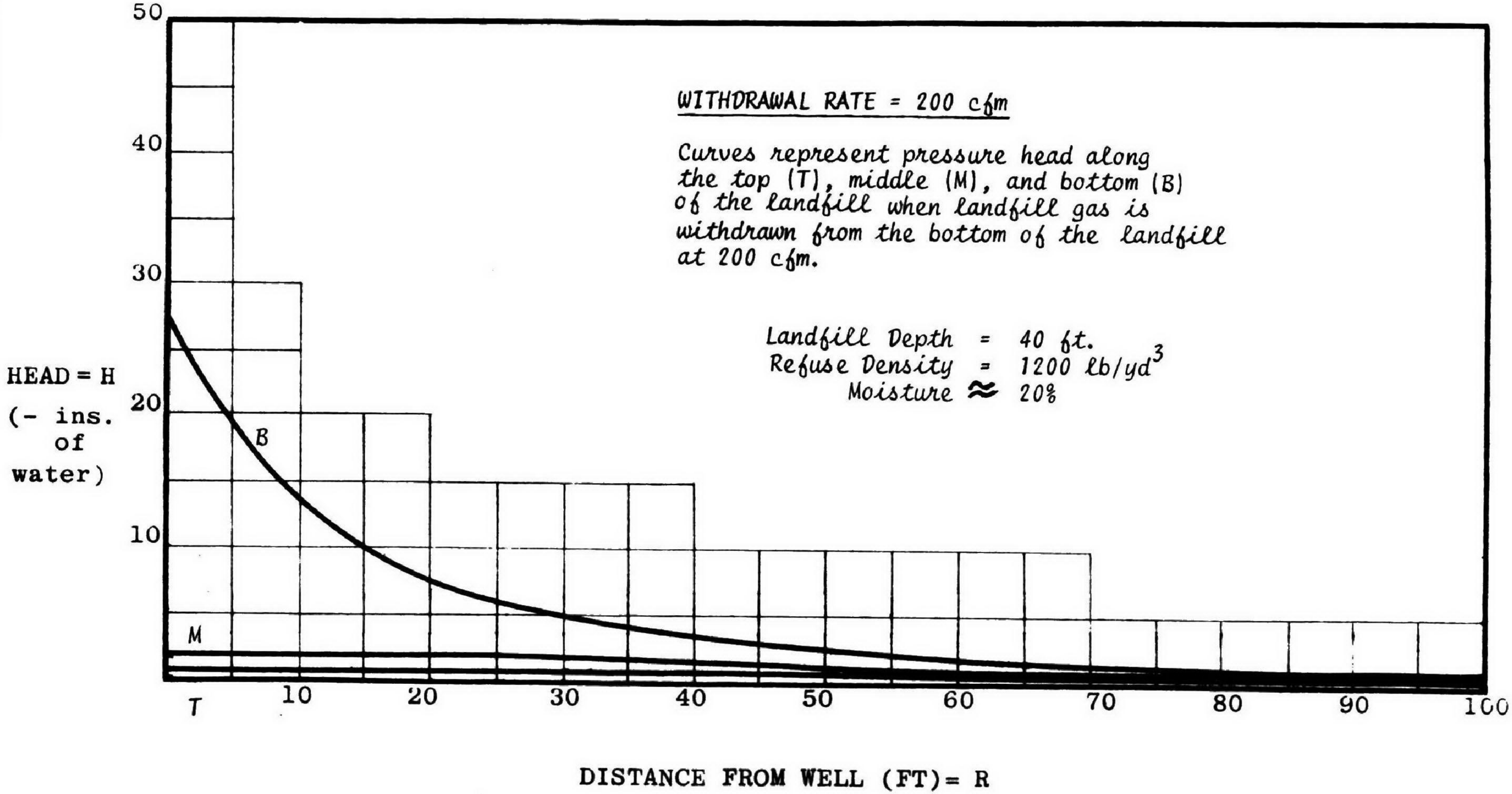
SHORELINE REGIONAL PARK




# HEAD LOSS CURVES

SHORELINE REGIONAL PARK

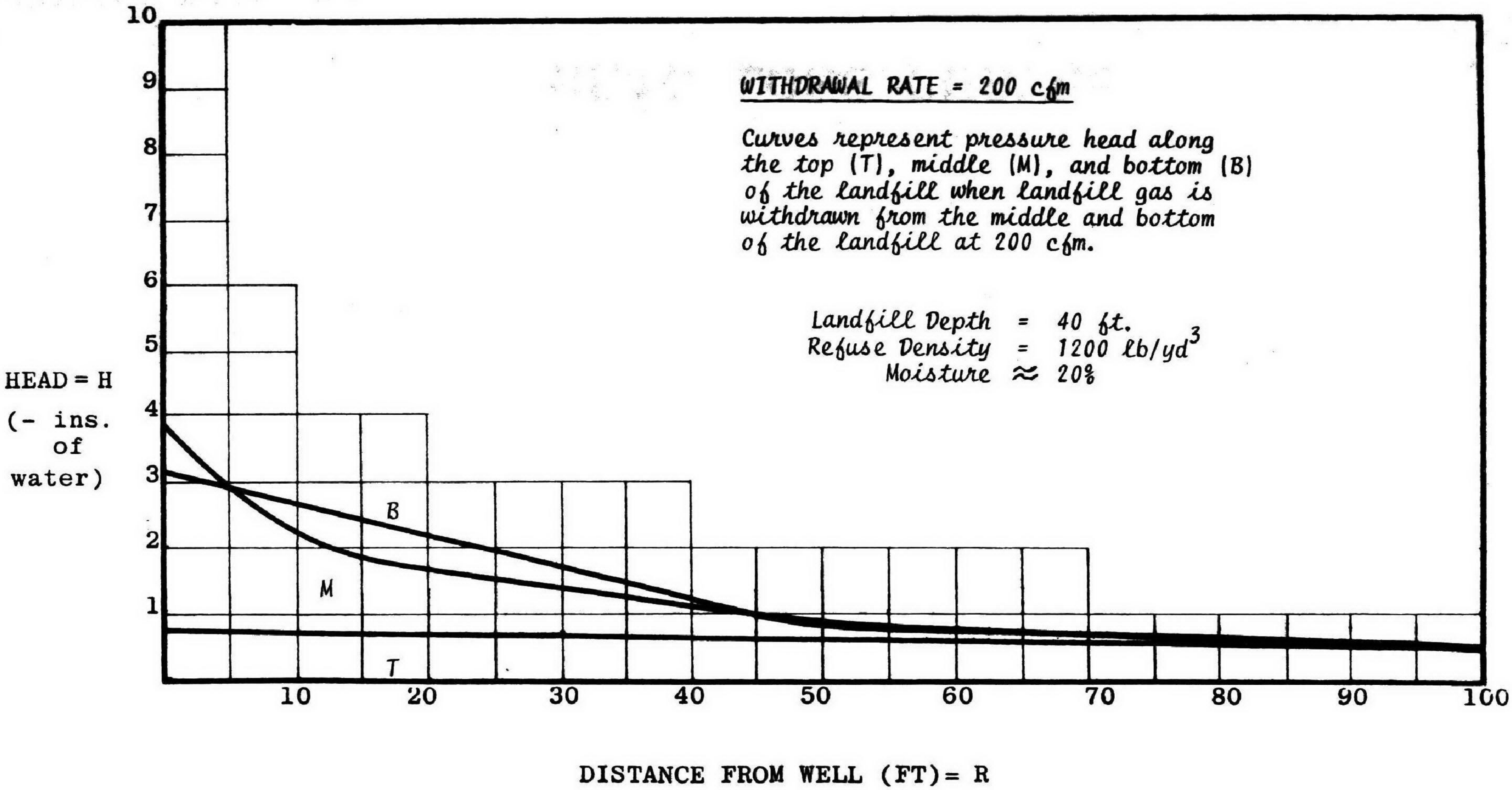
PLATE 17




# HEAD LOSS CURVES

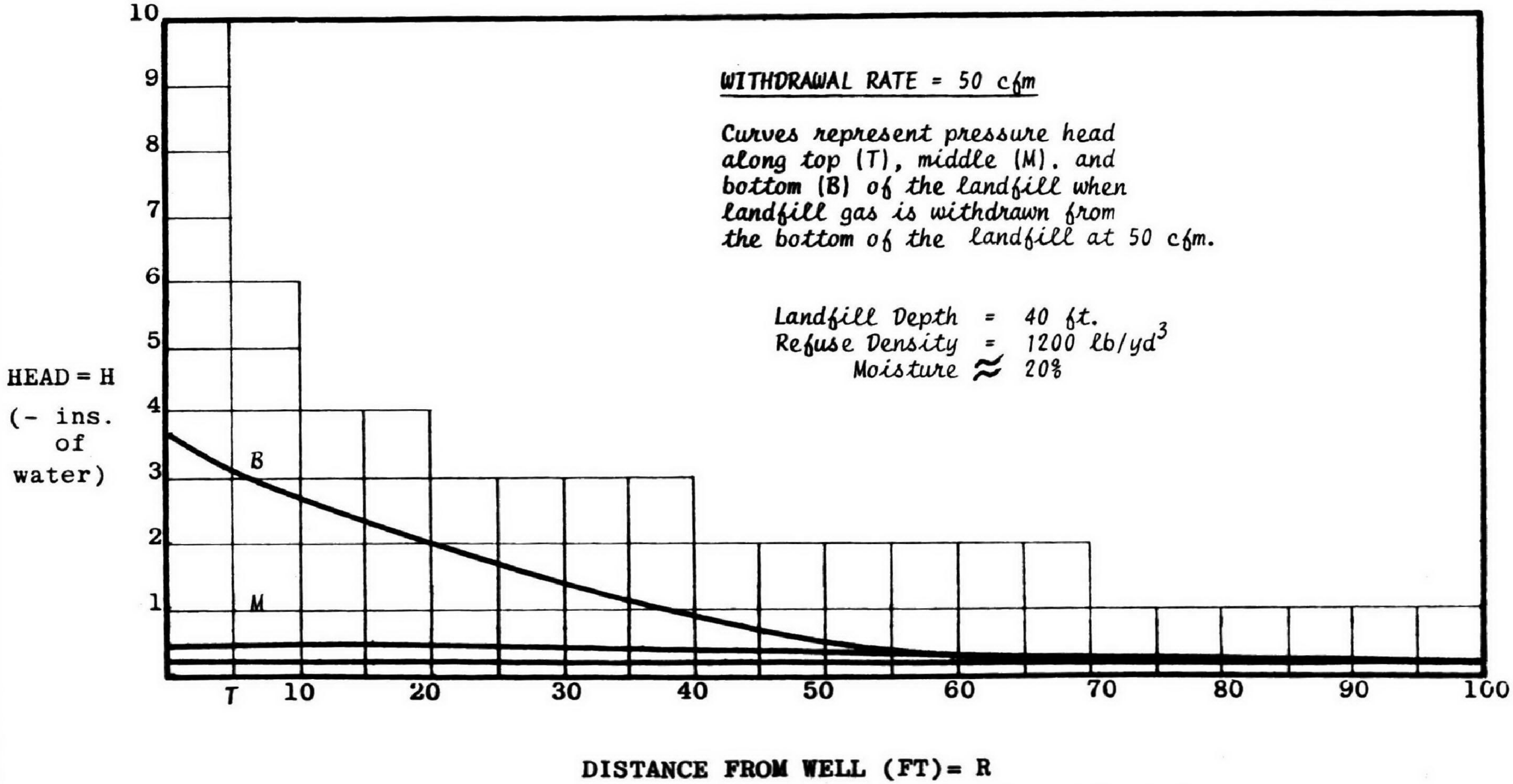
SHORELINE REGIONAL PARK

PLATE 18



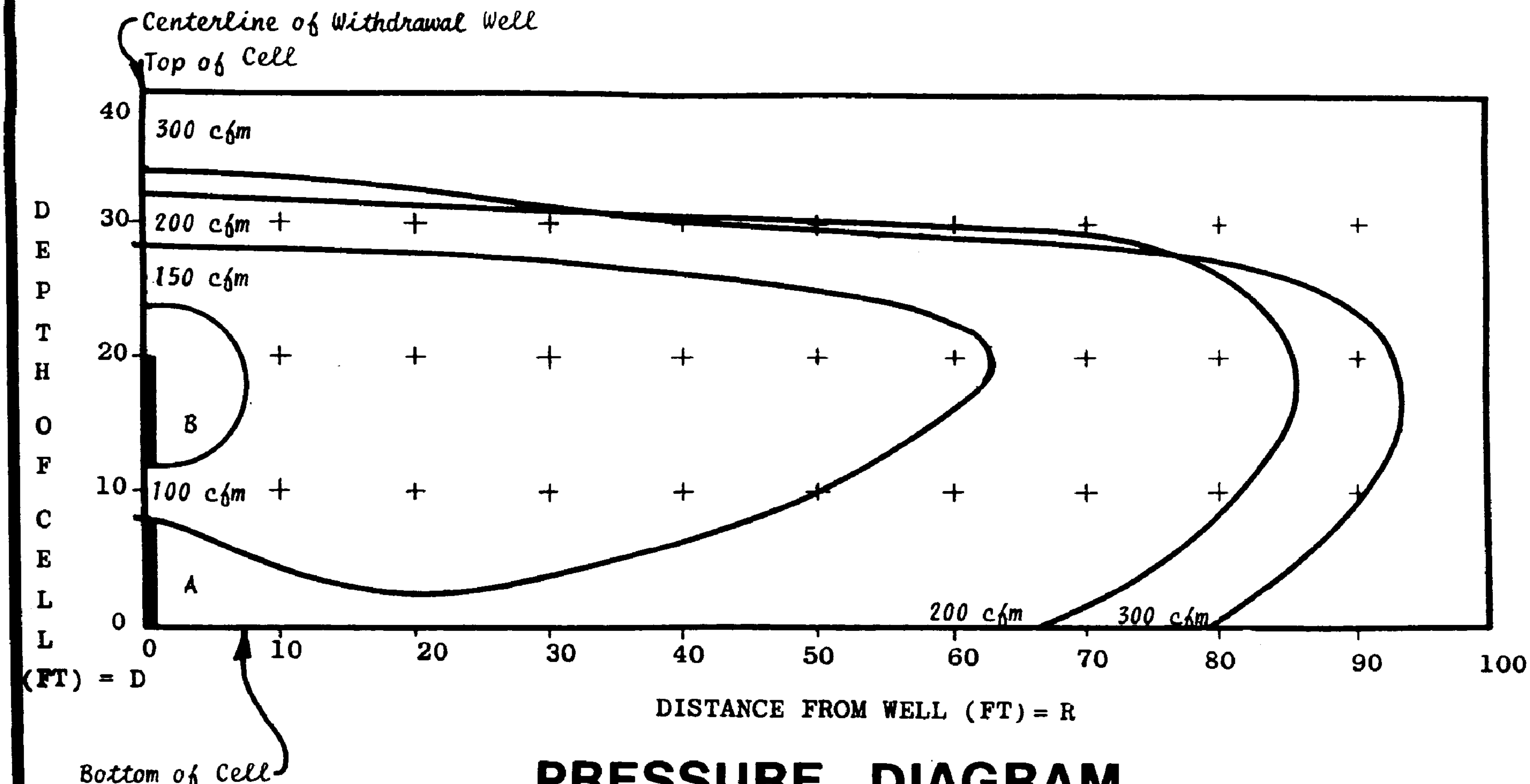

# HEAD LOSS CURVES

SHORELINE REGIONAL PARK




# HEAD LOSS CURVES

SHORELINE REGIONAL PARK

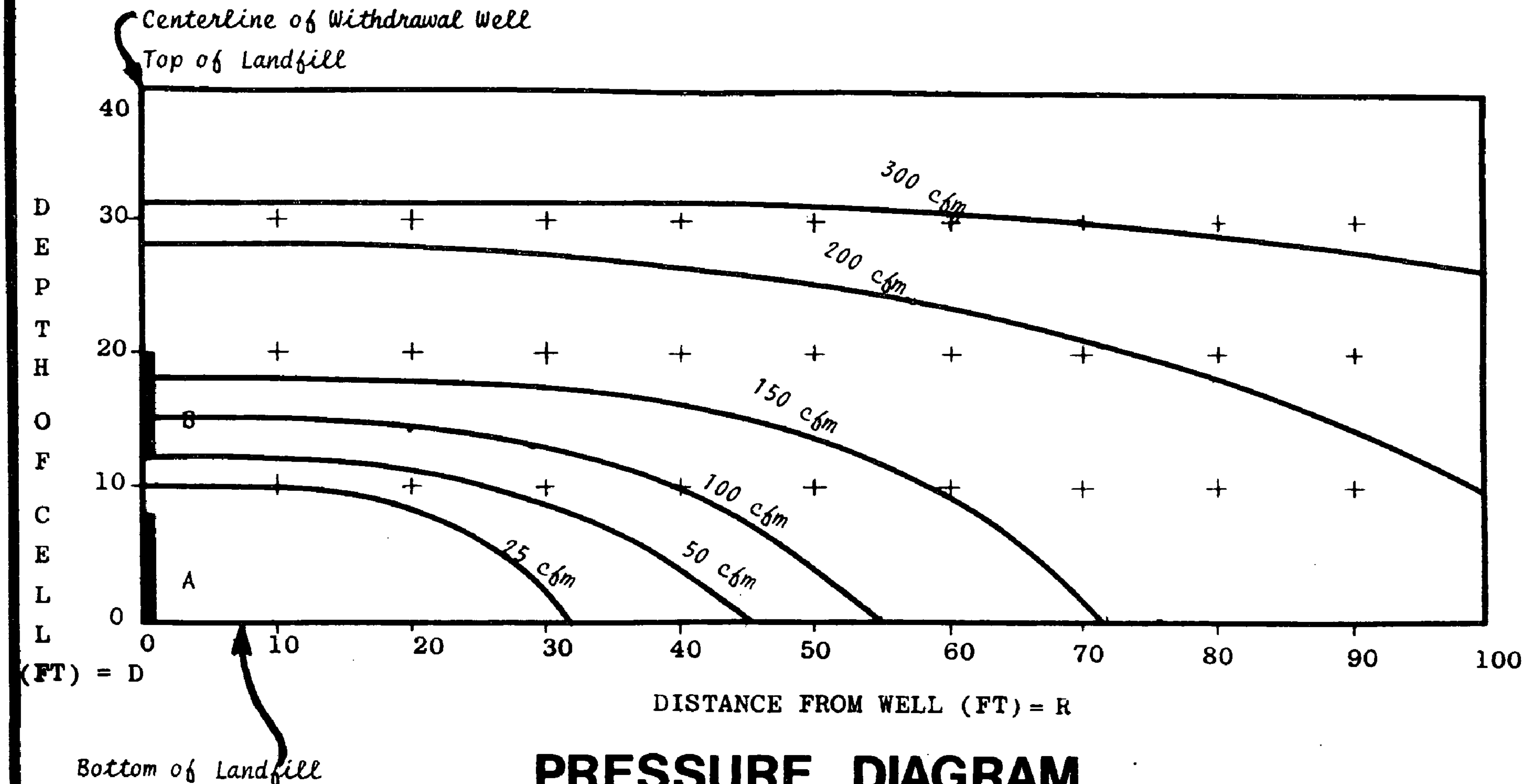



# PRESSURE DIAGRAM

*for one-inch water pressure contour at different withdrawal rates when landfill gas is withdrawn at Point B.*

PLATE 21

SHORELINE REGIONAL PARK

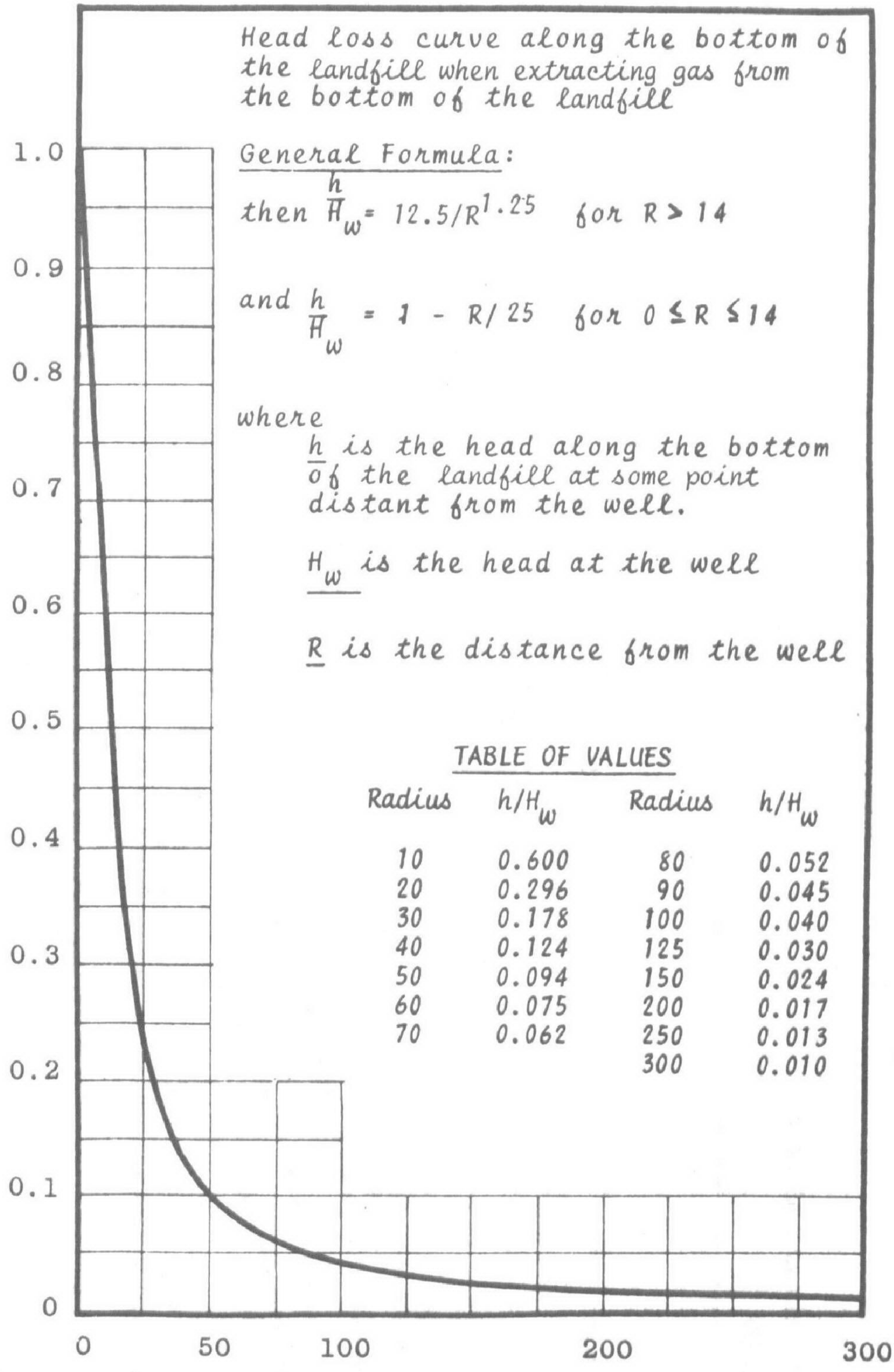



# PRESSURE DIAGRAM

*for one-inch water pressure contour at different withdrawal rates when landfill gas is withdrawn at Point A.*

SHORELINE REGIONAL PARK

PLATE 22




Head loss curve along the bottom of the landfill when extracting gas from the bottom of the landfill

General Formula:

then $\frac{h}{H_w} = 12.5/R^{1.25}$ for $R > 14$

and $\frac{h}{H_w} = 1 - R/25$ for $0 \leq R \leq 14$

where

$h$ is the head along the bottom of the landfill at some point distant from the well.

$H_w$ is the head at the well

$R$ is the distance from the well

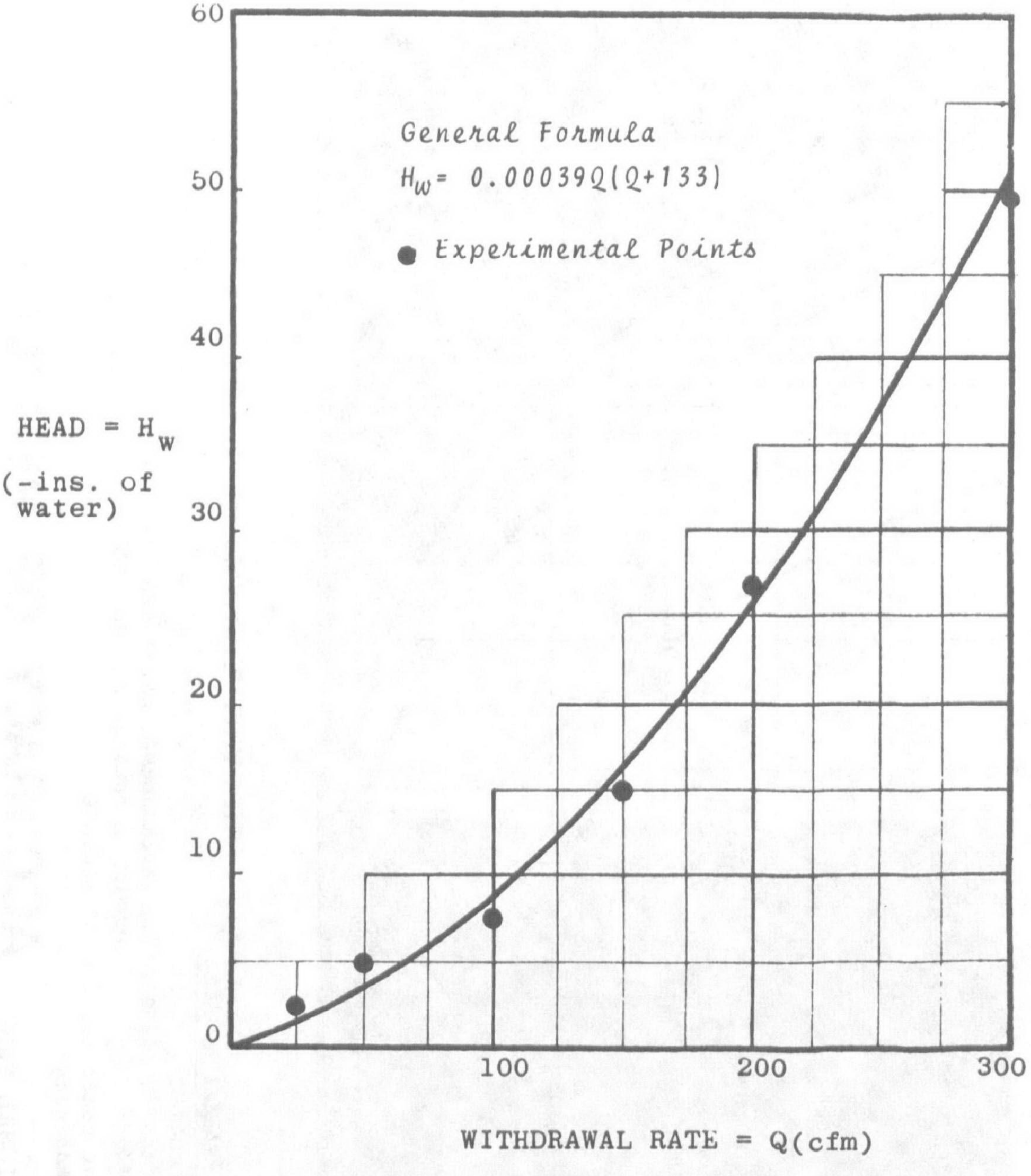
TABLE OF VALUES

| Radius | $h/H_w$ | Radius | $h/H_w$ |
|---|---|---|---|
| 10 | 0.600 | 80 | 0.052 |
| 20 | 0.296 | 90 | 0.045 |
| 30 | 0.178 | 100 | 0.040 |
| 40 | 0.124 | 125 | 0.030 |
| 50 | 0.094 | 150 | 0.024 |
| 60 | 0.075 | 200 | 0.017 |
| 70 | 0.062 | 250 | 0.013 |
| | | 300 | 0.010 |

DISTANCE FROM WELL (FT) = R

# HEAD LOSS CURVE

SHORELINE REGIONAL PARK

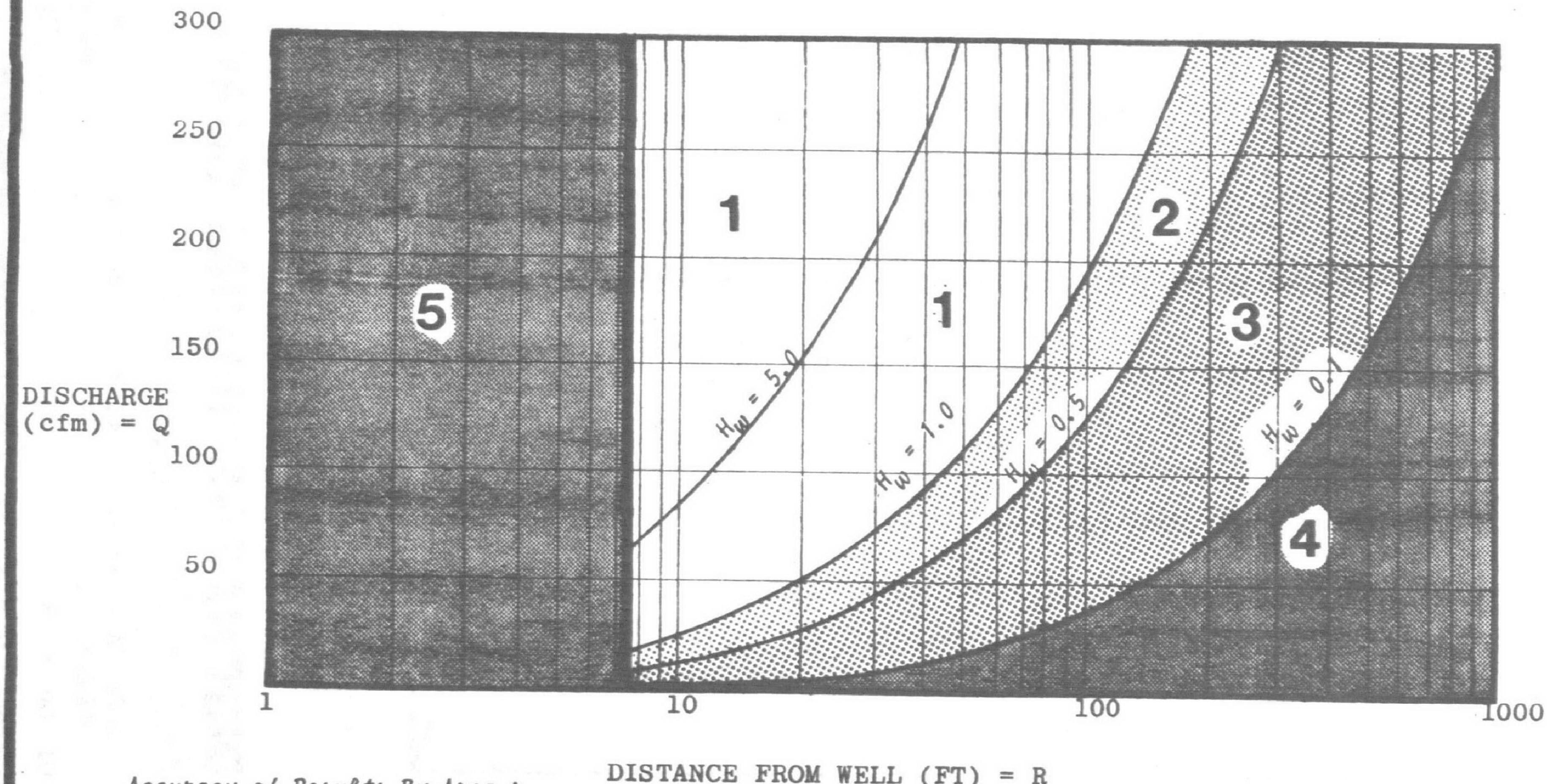



# DISCHARGE RATING CURVE

*for*

*Well 7A when withdrawing at bottom of landfill*

SHORELINE REGIONAL PARK




*Accuracy of Results By Area* *

1. *Accurate*
2. *Slightly effected by environment, pressures measurable*
3. *Effected by environment, inconsistent measurements*
4. *Pressures too low to measure*
5. *Imaginary*

*Derived empirically.

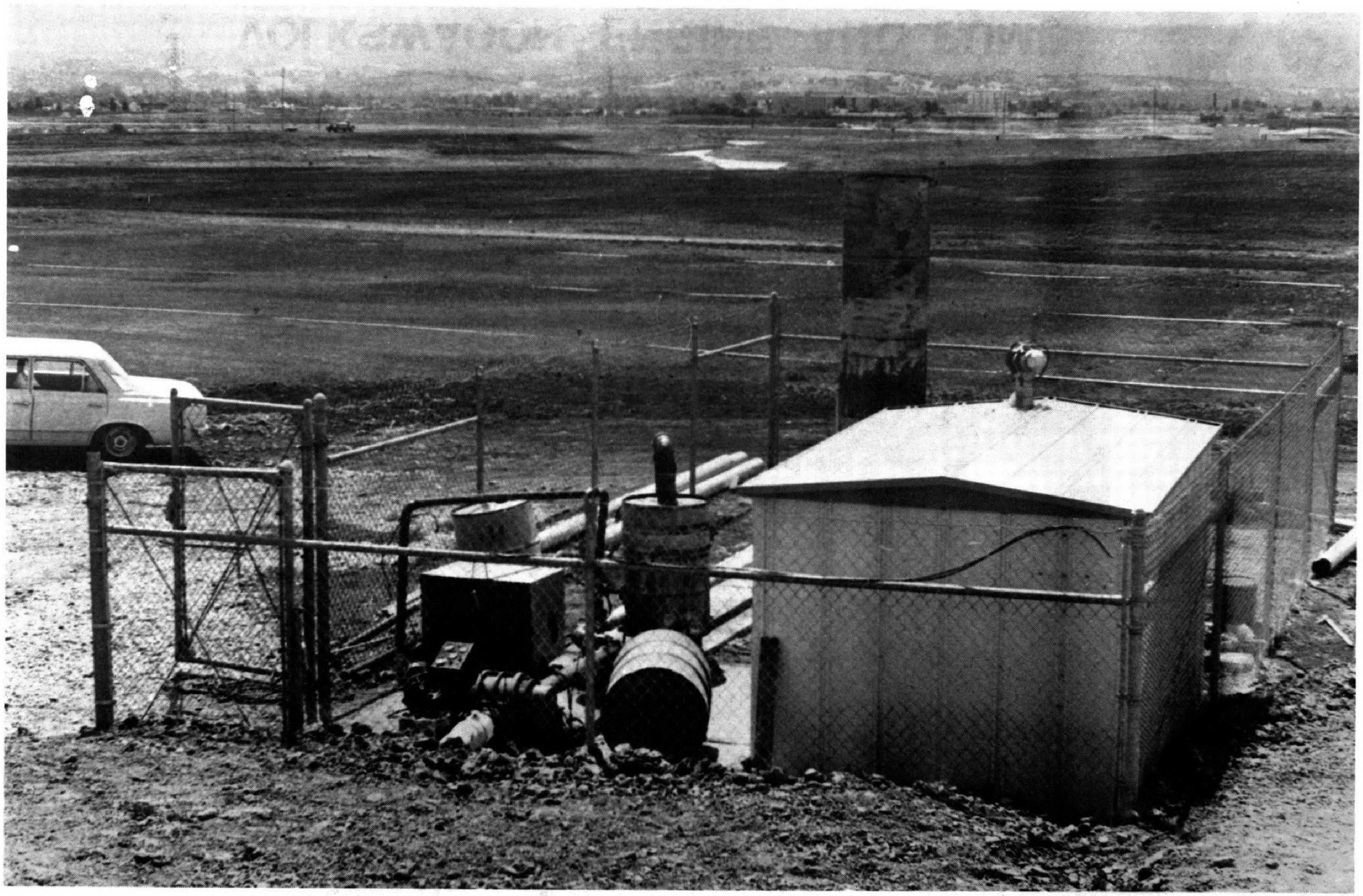
SHORELINE REGIONAL PARK

# ACCURACY OF RESULTS

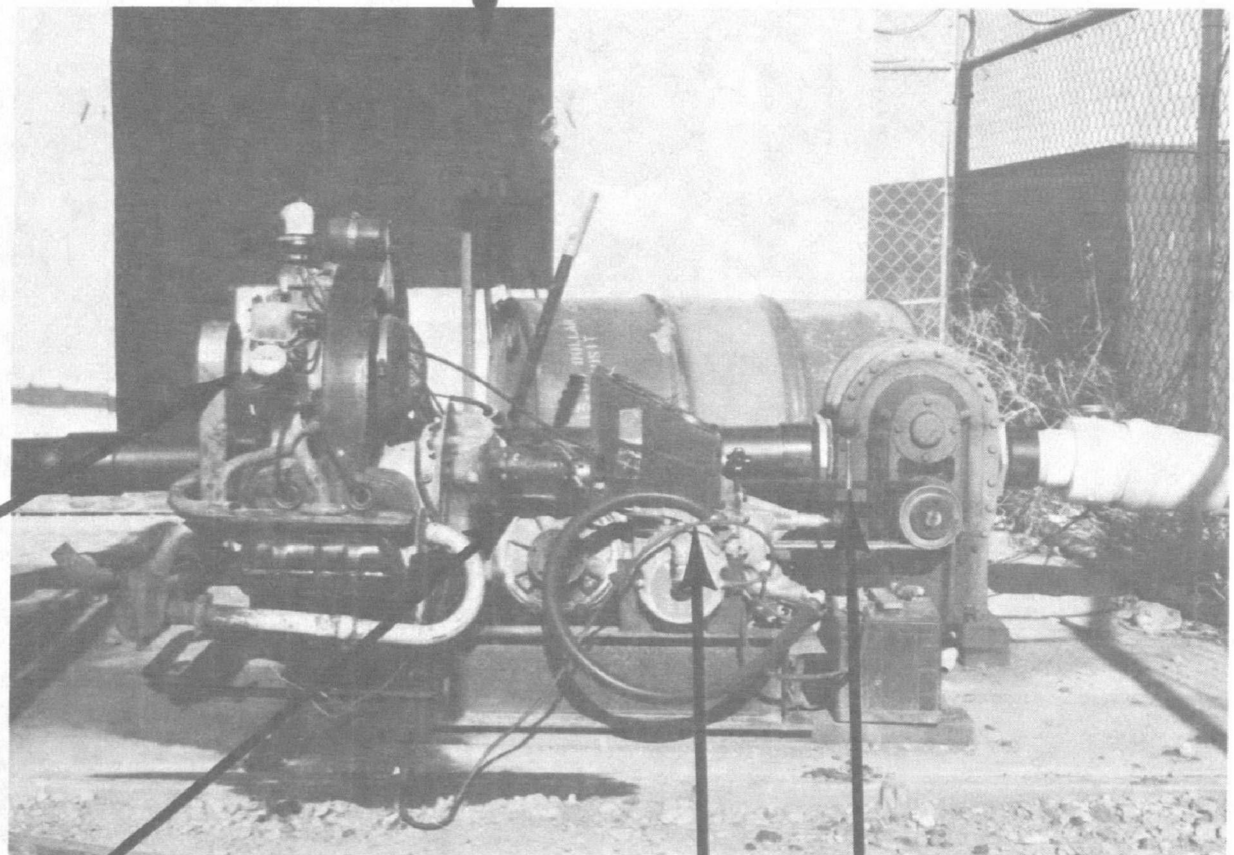
PLATE 25

PICTURE 1

PUMPING AND MONITORING FACILITY



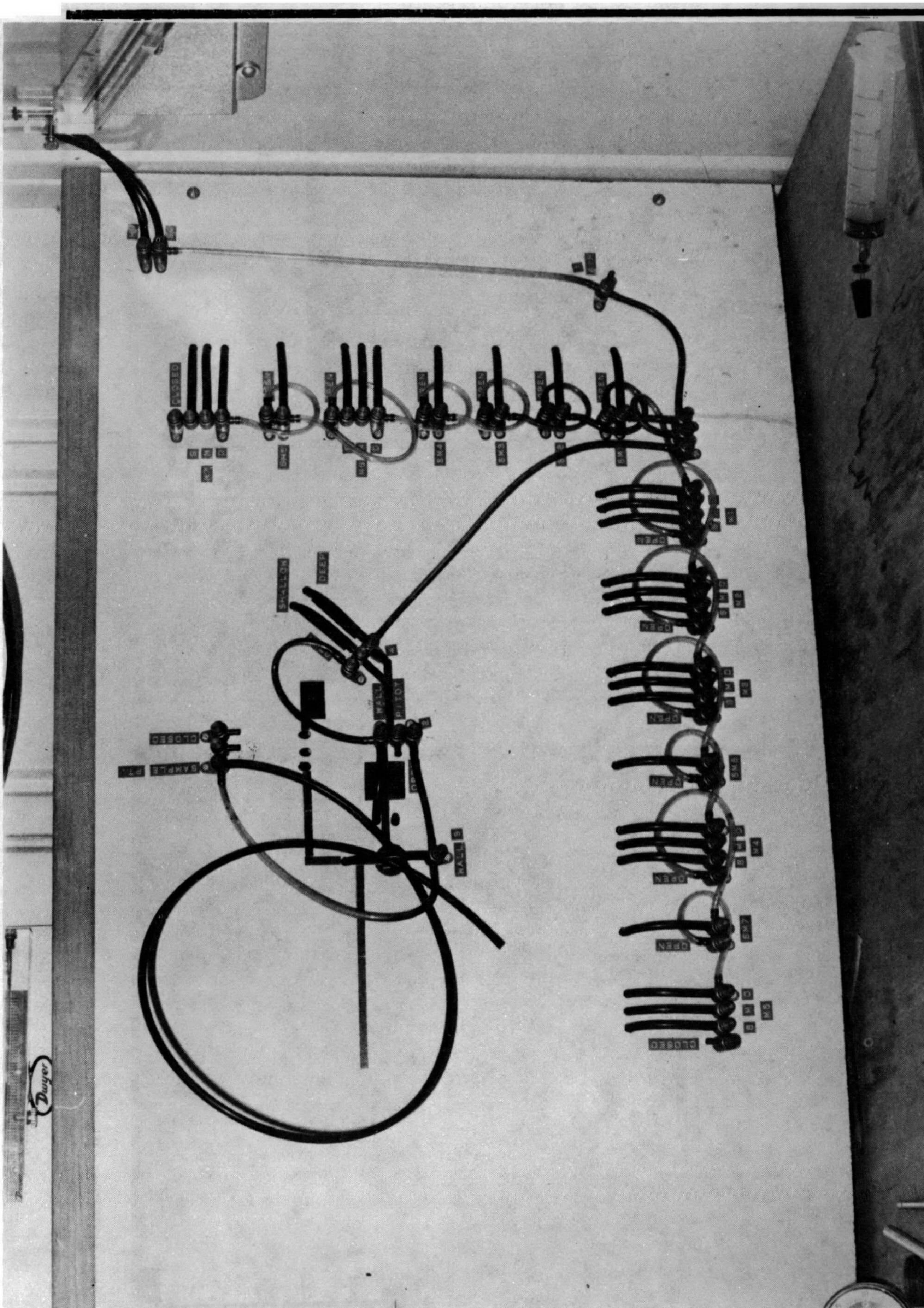
SHORELINE REGIONAL PARK




# VOLKSWAGON ENGINE AND PUMP

SHORELINE REGIONAL PARK

PICTURE 2

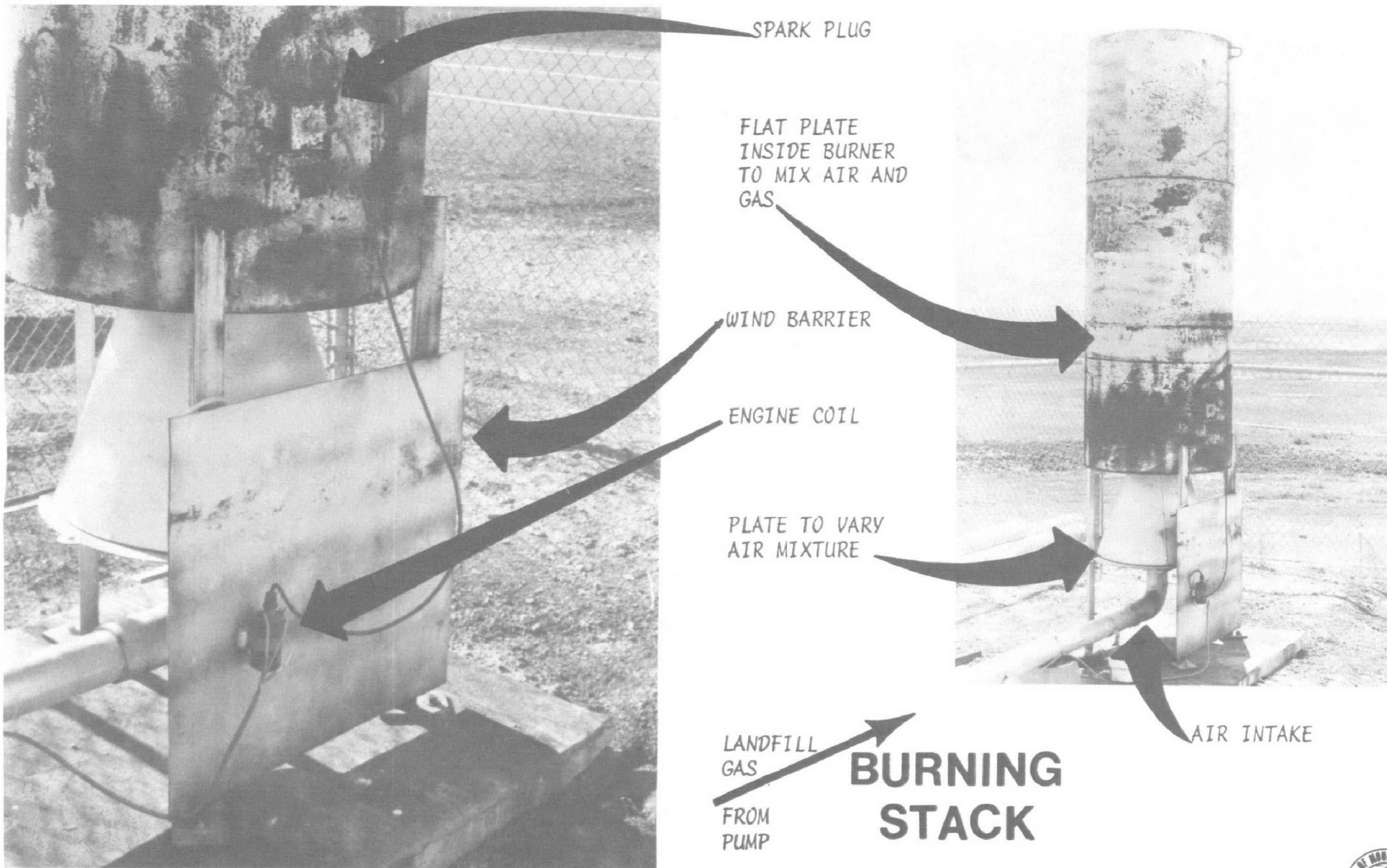



SHORELINE REGIONAL PARK

GAS PRESSURE MONITORING BOARD



PICTURE 3




SHORELINE REGIONAL PARK

PICTURE 4

# APPENDIX

## PART A - PROBLEMS, DELAYS, AND CHANGES

### Problems and Delays

No company had three pumps available for immediate delivery, and we were faced with a 3- to 8-month waiting period for fabrication. It took 2 weeks of calling to different manufacturers to get 3 pumps that matched our specifications and were in stock.

There was an 8-month delivery date for electrical motors and a 2-month delivery date for a gasoline engine. Therefore, Volkswagon engines were chosen since they had the right horsepower range and are air cooled.

The piping for the withdrawal wells had a 10-week delivery date which was the shortest time that could be found. The monitoring equipment had a 2-month delivery date.

Due to requirements of the City of Mountain View Charter, construction of the station had to be opened to competitive bidding. Normal scheduling would have delayed the project into winter and could have delayed the project for 6 months; however, the scheduling was shortened to 1-month which allowed construction to proceed prior to winter.

Testing prior to the initiation of this project indicated that an internal combustion engine would run on refuse gas; however, there were problems with keeping the Volkswagon engine continuously running on the refuse gas. The problem appeared to be the spark plugs and/or the regulator, but the problems were never solved and gasoline was used to fuel the engines.

Preliminary tests proved that the refuse gas could be ignited in the burning stack by a spark plug situated on the side of the stack. The spark plug would receive impulse charges from a coil that was connected in series with the coil for the engine which ran the pump. However, when the same arrangement was installed using the Volkswagon engine, the second coil lowered the energy output of the engine coil which resulted in the fouling of the engine spark plugs. An electronic vibrator (run off the engine battery) has been substituted for the points in the engine and is providing impulse charges, via a coil, to the stack spark plug. This system kept failing and an adequate system was never obtained.

The landfill gas was at or near saturation levels and the water in the gas caused many problems. By placing a demister in the line prior to the Volkswagon engine, it alleviated the problem of water accumulating in the pressure regulator. The demister was a 55-gallon drum stuffed with fiberglass screening. The gas was pumped into the drum, which stood on end, at the bottom, tangentially, and exited out the top in the middle of the flat end. The water also collected in the pressure monitoring tubes that lead to the monitoring board. The lines had to be continually cleared before pressure measurements could be made. To avoid the water collecting in the pipes from the wells to the pumps, the pipes were sloped back to the wells.

Changes

From the second interim annual report of the Sonoma County Refuse Test Cells, Solid Waste Disposal Demonstration Grant, Project G06-EC-00351, prepared by EMCON Associates, it is shown that the leachate pH is contaminated by soluable gases, especially carbon dioxide, and remains around 5. When the leachate was sampled from the collector at Well 7A, it was found to be 4.6. This indicated that the conditions were similar to the test cells in Sonoma and that the pH would not be a good indicator of the change of digestion processes in the landfill. Therefore, scheduled testing of pH was discontinued.

From the report mentioned above, it was apparent that more information about the gas production could be obtained by a continual complete analysis of the refuse gas as it was being pumped from the landfill. The following testing procedure was added prior to the commencement of the pumping.

a. Prior to initial pumping at all 4 wells, a complete gas analysis was made at each production well point and pressure point.

b. During pumping a complete analysis of the gas was made twice a day, at 10 a.m. and 3 p.m., twice a week.

c. After the short-run testing was completed, the procedure in a. above was repeated.

d. During long-range pumping, a complete analysis was run twice a week, i.e., on Tuesday and Friday.

e. After the long-run test was completed, the procedure in a. was repeated.

## PART B - DATA

Testing on production Well 7A started on December 10, 1974. From December 10 through December 12, gas was sampled from each pressure point and well point and a complete analysis was run.

From December 15 through December 26, gas was pumped from the deep well point at 100 cfm, 150 cfm, 200 cfm, and 300 cfm. From January 6 and 7, gas was pumped from the shallow well point at 100 cfm, 150 cfm, 200 cfm, and 300 cfm. From the test results from December 15 through January 9, it appeared that the best pumping rate might be 200 cfm; so on January 9, gas was pumped from both the deep and shallow well points at 200 cfm. After the short-run testing on January 17, gas was sampled from each pressure point and well point for the monitoring Well 7A and a complete analysis was run.

On February 11, 1975, the long-range continuous pumping started. The initial pumping rate was 200 cfm, and the gas was withdrawn from the bottom of the landfill. Plate 14 shows the results of the pumping. The withdrawal rate was continuously lowered until a steady composition was obtained at 50 cfm.

All gas analyses for the above follows.

## PART C - GAS DYNAMICS IN THE SANITARY LANDFILL

The refuse chamber is sealed on the bottom and sides by 5 feet of clay and on the top by 1 foot of clay. The clay has a permeability to water of at least $10^{-7}$ cm/sec. The area around Well 7B has 1 foot of clay while the area around Well 7A has an additional 2 feet of similar clay with some sludge mixed into it.

Reference is made to the State of California Water Quality Control Board publication entitled, "IN-SITU Investigation of Movements of Gases Produced from Decomposing Refuse," dated 1965, prepared by Engineering-Science, Inc., Oakland, CA. In the report, the following equations are given for diffusion of gases through soils:

$$q = \frac{C D_P}{L} \qquad \text{A1}$$

$$\frac{D_p}{D_o} = 0.66P \qquad \text{A2}$$

Where q = net transfer rate in feet per day.

C = gas concentration in top layer of landfill in fraction by volume.

$D_p$ = diffusivity of a gas in soil in square feet per day.

$D_o$ = diffusivity of a gas in free space in square feet per day.

L = thickness of soil cover in feet.

P = porosity of soil cover as a ratio.

The transfer rate will vary using the temperature, pressure, and the gas. Using the following reasonable assumptions taken from this report and our data,

Temperature = 68°F

$D_o(CO_2)$ = 15 sq.ft./day

$D_o(CH_4)$ = 20.7 sq.ft./day

Porosity = 30% (60% porosity - 30% moisture)

$C\ (CO_2)$ = 30%

$C\ (CH_4)$ = 35%

and

$$\frac{D_P}{D_o} = 0.66P = 0.198$$

the following calculations for the diffusion rates for methane and carbon dioxide can be made.

for $CO_2$: $$q_{CO_2} = \frac{(.30)\ (15\ ft.^2/day)\ (0.198)}{3\ ft}$$

$$q_{CO_2} = 0.297\ ft./day$$

for 1 acre: $$Q_{CO_2} = (0.297\ ft./day)\ (43560\ ft.^2/acre)\ (1\ acre)\ (1\ day/24\ hours)\ (1\ hour/60\ min.)$$

$$= 8.98\ cu.\ ft./min.$$

for $CH_4$: $$q_{CH_4} = \frac{(.35)\ (20.7)\ (0.198)}{3\ ft.}$$

$$q_{CH_4} = 0.478\ ft./day$$

for 1 acre: $$Q_{CH_4} = (0.478\ ft./day)\ (43560\ ft.^2/acre)\ (1\ acre)\ (1\ day/24\ hours)\ (1\ hour/60\ min.)$$

$$=14.46\ cu.ft./min.$$

Therefore, for every acre of landfill, methane, and carbon dioxide gases will diffuse through the seal at a combined rate of approximately 23.4 cu. ft./min. It is important to realize that diffusion does not require a pressure head. Therefore, when the barometric pressure is dropping, the extracellular pressure is lower than the intracelluar pressure, and additional landfill gas is forced into the atmosphere. When the barometric pressure is rising, the extracellular pressure is greater than the intracelluar pressure and the diffusion will not stop until sufficient pressure head is developed to reverse the flow.

As a side note, nitrogen and oxygen are in greater concentration in the atmosphere than in the landfill; thus diffusion of these gases into the landfill occurs. A rise in barometric pressure aides the diffusion and a drop in barometric pressure reduces or negates the diffusion effect.

In an attempt to verify in the laboratory, the porosity of the clay seal, a 6-inch plastic pipe with 3 feet of compacted clay in it was subjected to minus 2 inches of water pressure. Within 15 minutes, the pressure had dissipated. The flow was too low to measure with our instruments which can measure to a 0.1 standard cu. ft./hr. which is 72.6 cu. ft./min. per acre.

## Climatic Influence

The Department of Commerce in Oakland has indicated that the barometric pressure in the Bay Area has a seasonal variance from 30.5 inches of mercury (414.80 inches of water) to 29.5 inches of mercury (401.20 inches of water) with a mean of 29.92 inches of mercury (406.91 inches of water). The average rate of change in barometric pressure is 0.08 inches of mercury (1.09 inches of water) per hour with a maximum rate of change of 0.1 inches of mercury (1.36 inches of water) per hour. The rate of change in pressure could be faster; however, the mountain ranges surrounding the Bay tend to disturb and mix weather fronts as they move into the Bay.

TABLE A1

Static Pressure Readings

Taken on 11/22/74 around Well 7A

| Time | A.M. | P.M. |
|---|---|---|
| Barometric Pressure (BP) | 410.60 ins. of $H_2O$ | 410.19 ins. of $H_2O$ |
| Intracell Pressure (IP) (Average) | 410.60 ins. of $H_2O$ | 410.23 ins. of $H_2O$ |
| (BP) - (IP) | 0 | -0.04 ins. of $H_2O$ |

Table A1 summarizes the information in which it can be seen that the average landfill pressure adjusted to the changing barometric pressure except for 0.04 inches of water. The account for the equalization of pressure; the landfill is either changing in volume or the air and landfill gases are moving through the top clay seal which is 3-feet thick. From the information given in the previous part of the Appendix, it is evident that the landfill is breathing. Since the pressure equalization effect pertains to the full depth of the landfill, there is movement of gas even at the bottom of the landfill.

Table A2, at the end of this section, provides a partial picture of the effect the barometric pressure has on the gas extraction. The figures in Table A2 show that as the atmospheric pressure dropped, the negative pressures in the landfill increased. The pump is withdrawing gas at a negative 6 inches of water pressure at the bottom of the landfill at the well head designated 7Ad. The atmosphere is applying a gradually increasing negative pressure of 0.95 inches of water pressure from 5 p.m. to 9 p.m. With the atmospheric pressure dropping, pressures should increase positively in the landfill if air is not moving through the top seal. However, Table A2 shows that the atmosphere is competing with the pump for the landfill gas and resulting higher negative pressures are realized in the landfill.

As further evidenced, when Well 7A was pumped at 200 cfm, the nitrogen level inceased from 13.65% to 39.98% in the extracted landfill gas. A comparison of several points in the landfill is shown in Table A3.

TABLE A3

Percent of Nitrogen BEFORE/AFTER pumping at 200 cfm

| Distance from Well: | 15' | 30' | 60' | 100' |
|---|---|---|---|---|
| Top of Landfill | 28.98/79.73 | 58.23/84.83 | 42.59/79.27 | 61.98/63.63 |
| Bottom of Landfill | 2.51/10.99 | 8.51/41.06 | 27.93/58.05 | 5.80/34.81 |

The data in Table A3 clearly indicates that air, represented by the amount of nitrogen, was drawn into the landfill over a wide range of the landfill.

## TABLE A2

PRESSURE READINGS (Ins. of $H_2O$) WHEN WITHDRAWING LANDFILL GAS AT 75 CFM FROM WELL HEAD POINT 7Ad

| Time: | 5 p.m. | 6 p.m. | 7 p.m. | 8 p.m. | 9 p.m. | Change |
|---|---|---|---|---|---|---|
| Barometric Pressure: (Ins. of $H_2O$) | 408.95 | 408.41 | 408.14 | 408.14 | 408.00 | -0.95 |
| Well Head | | | | | | |
| *Shallow-7ASM1 | -0.11 | -0.13 | -0.16 | -0.26 | -0.29 | -0.18 |
| Middle -7As | -0.29 | -0.32 | -0.36 | -0.50 | -0.51 | -0.22 |
| Deep -7Ad | -6.0** | -6.0 | -6.0 | -6.0** | -6.0** | |
| At 15' from Well Head | | | | | | |
| Shallow-7AM1S | 0 | -0.10 | -0.25 | -0.43 | -0.31 | -0.31 |
| Middle -7AM1M | -0.39 | -0.44 | -0.47 | -0.58 | -0.63 | -0.24 |
| Deep -7AM1D | -3.48 | -3.60 | -3.70 | -3.75 | -3.84 | |
| At 30' from Well Head | | | | | | |
| Shallow-7AM2S | 0 | 0 | -0.15 | -0.22 | -0.26 | -0.26 |
| Middle -7AM2M | -0.24 | -0.28 | -0.32 | -0.45 | -0.48 | -0.24 |
| Deep -7AM2D | -1.34 | -1.41 | -1.49 | -1.58 | -1.63 | |
| At 60' from Well Head | | | | | | |
| Shallow-7AM3S | 0 | 0 | 0 | 0 | 0 | 0 |
| Middle -7AM3M | -0.23 | -0.28 | -0.32 | -0.44 | -0.49 | -0.26 |
| Deep -7AM3D | -0.41 | -0.48 | -0.52 | -0.65 | -0.69 | -0.28 |
| At 100' from Well Head | | | | | | |
| Shallow-7AM4S | 0 | 0 | 0 | -0.28 | -0.31 | -0.31 |
| Middle -7AM4M | 0 | 0 | 0 | 0 | 0 | |
| Deep -7AM4D | -0.04 | -0.08 | -0.08 | -0.26 | -0.28 | -0.24 |
| At 200' from Well Head | | | | | | |
| Shallow-7AM5S | -0.41 | -0.38 | -0.45 | 0 | -0.39 | +0.02 |
| Middle -7AM5M | 0 | 0 | 0 | 0 | 0 | |
| Deep -7AM5D | +0.19 | +0.14 | +0.02 | 0 | -0.75 | -0.94 |

*Refer to Plate 2 for visual location of well points within landfill.

** Adjusted Pressures

Actual Pressures are:

5 p.m. -6.2
8 p.m. -6.4
9 p.m. -6.1

Pressures in these columns adjusted by percent so that comparison can be made.

## PART D - LO-OX INDUCTION SYSTEM

Air entering the landfill is limiting the amount of gas that can be removed from the landfill from a vertical well. If the amount of air can be reduced or eliminated, increased gas production should result.

Air enters the landfill through diffusion and pressure. Diffusion will only stop if concentrations on both sides of the top seal are equal or when pressure within the landfill offsets the diffusion of air into the landfill. Both solutions are incompatible with the current method of withdrawal. Therefore, diffusion will occur and adjustments would have to be made in the cleaning facilities to allow for this air.

Air entrainment via pressure differential across the top seal can be stopped. The present procedure withdraws the landfill gas at a rate which creates a slightly negative pressure just under the top seal. When the atmospheric pressure is constant, increasing, or very slightly decreasing, air will enter the landfill due to the negative pressure in the landfill.

The suggested approach to relieve the negative pressure is to recycle some of the extracted gas, called LO-OX because of its low oxygen content, through an upper-cellular pressure equalization system, UPES. The UPES will consist of piping leading from the positive pressure side of the withdrawal pump to the refuse/top seal interface. Valving would allow the LO-OX gas to enter the piping at the pump at a little above atmospheric pressure. The negative pressure at the interface would draw the LO-OX gas through the pipes and into the landfill. The horizontal stratification of the refuse would allow the LO-OX gas to expand horizontally and effectively reduce the amount of air entering the refuse.

By introducing LO-OX gas at the refuse/top seal interface, the amount of oxygen and nitrogen entering the landfill is reduced. For instance, without LO-OX gas, air entering the landfill contains 80% nitrogen and the extracted landfill gas contains 20% nitrogen. If this LO-OX gas is recycled using UPES, the LO-OX gas with 20% nitrogen would replace air with 80% nitrogen and a landfill with a lower nitrogen content would be obtained. Nitrogen cannot be completely removed, however, due to diffusion.

This system was installed at withdrawal Well 7A but no substantial testing was done.

## PART E - COSTS

For informational purposes, the following are costs related to the project in 1974 dollars.

| | | |
|---|---|---|
| 1. | 3 Positive Displacement Pumps, 200cfm | $2500 (total) |
| 2. | 3 Volkswagon Engines, assembled | $2800 (total) |
| 3. | Complete Pumping Station* | $4400 (total) |
| 4. | Complete Extraction Well | $13.00/ft. |

* Include grading, concrete pad, monitoring shack, fencing, and internal piping.

# PART F - CALCULATIONS

## Total Gas Production Rate

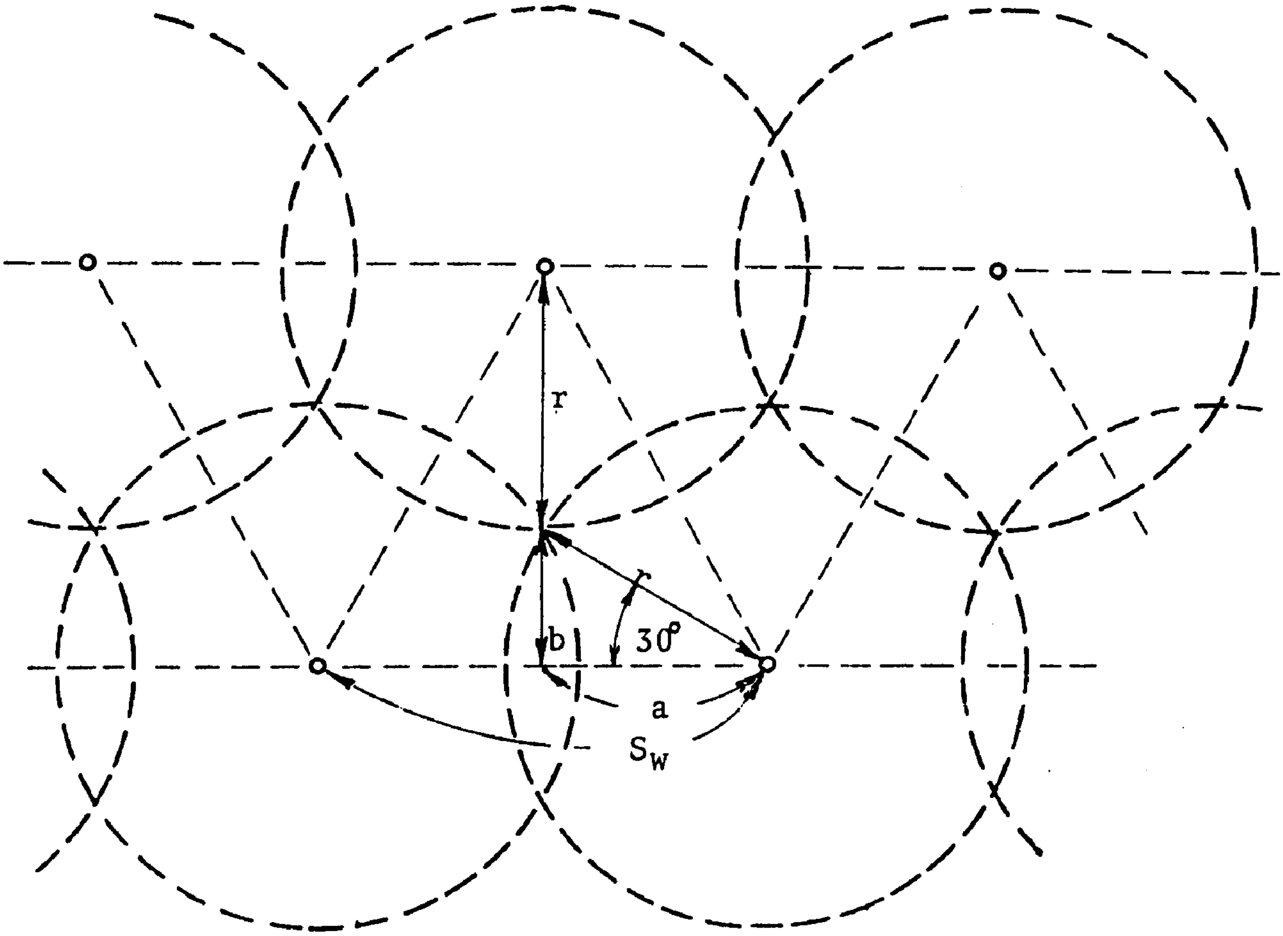



Figure F1

1) Well Spacing

$$S_w = 2a = 2(r \cos 30^\circ)$$

$$= (2)(130 \text{ ft.})(0.866)$$

$$S_w = 225.17 \text{ ft.}$$

2) Withdrawal rate per acre is based on one half well per base triangle with sides equal to 225 ft.

a) Triangle Area, $A_t$

$$A_t = \tfrac{1}{2}S_w(r + b) = \tfrac{1}{2}S_w(r + a \tan 30^\circ)$$

$$= (\tfrac{1}{2})(225 \text{ ft.})\ (130\text{ft.} + (112.5\text{ft.})(0.577))$$

$$A_t = 21{,}932.09 \text{ ft.}^2$$

b) Withdrawal Rate/acre, $Q_{acre}$

$$Q_{acre} = \tfrac{1}{2}q_{well} \frac{43560\text{ft.}^2/\text{acre}}{A_t}$$

$$= (\tfrac{1}{2})(50\text{cfm}) \frac{(43560\text{ft.}^2/\text{acre})}{21932\text{ft.}^2}$$

$$Q_{acre} = 49.7 \text{ cfm/acre}$$

3) Total Site Production, $Q_{site}$

$$Q_{site} = Q_{acre}A_{site}$$

$$= (49.7 \text{ cfm/acre})(150 \text{ acres})$$

$$Q_{site} = 7455 \text{ cfm}$$

or

$$Q_{site} = (7455\text{cfm}) \frac{(60 \text{ min.})}{(1 \text{ hr.})} \frac{(24 \text{ hrs.})}{(1 \text{ day})} \frac{(1 \text{ mmcfm})}{(1{,}000{,}000 \text{ cfm})}$$

$$Q_{site} = 10.7 \text{ mmcfd}$$

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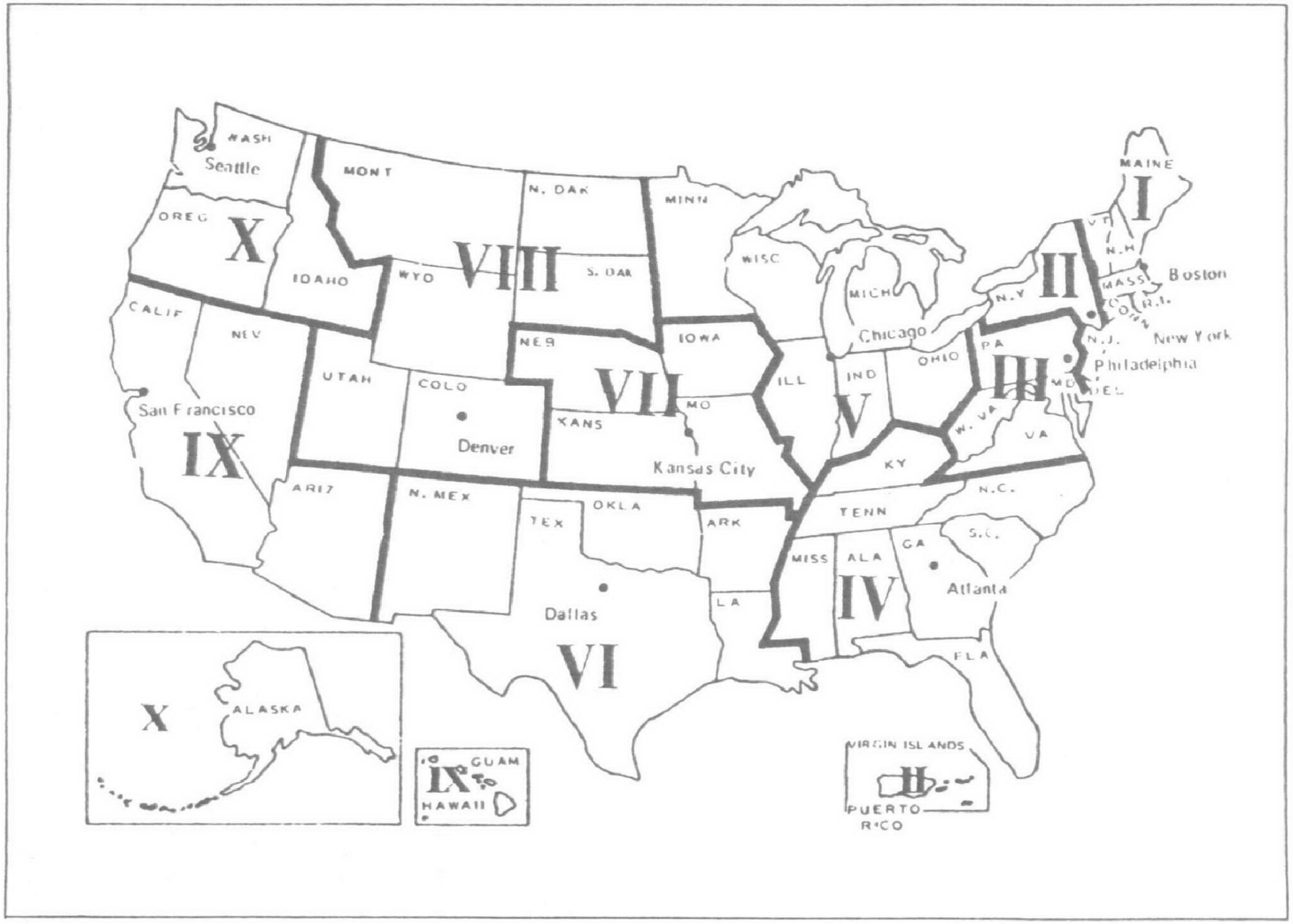


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