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Philadelphia PA 19103-1699

May 21, 1984

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Mr. Richard Shiver
North Carolina Department of
Natural Resources &
Community Development
7225 Wrightsville Avenue
Wilmington, NC 28403

Dear Mr. Shiver:

We enclose a copy of Carlyle Gray and Associates, Inc. final report on the cleanup of paraxylene at Wilmington, NC.

Very truly yours,

Earl C. Beil
Consultant

ECB:dmc

CC: ARTHUR MOUBERRY ON 5-29-84

RMM5 1

CARLYLE GRAY & ASSOCIATES, INC.

CONSULTING GEOLOGISTS
241 E. KING ST.
LANCASTER, PA. 17602

GROUND WATER EVALUATIONS
MINERAL RESOURCE STUDIES

(717) 397-7833

ENVIRONMENTAL GEOLOGY
ENGINEERING GEOLOGY

FINAL REPORT

ON

CLEANUP OF PARAXYLENE SPILL

AT

FORMER SUN REFINING AND MARKETING TERMINAL

WILMINGTON, NORTH CAROLINA

RECEIVED

MAY 29 1984

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FINAL REPORT: WILMINGTON TERMINAL, SUNMARK INDUSTRIES

Location and Topography

The Koch Fuels Wilmington Terminal (formerly owned by Sunmark Industries) is located on River Road, about 3 miles south of the center of the City of Wilmington. The part of the terminal discussed in this report is east of River Road and about 2,000 feet from the bank of the Cape Fear River. The topography at the terminal is gently rolling, and probably represents stabilized sand dunes, considerably modified by construction activities. There are no distinct surface drains. Drainage in the central part of the terminal area is effected by tile drains emptying into a main that flows westward into a small lagoon on the North Carolina State Ports property on the west side of River Road. (See Figure 1.)

The tanks are diked, and there is no provision for drainage from the dikes. All precipitation falling inside the dikes must evaporate or infiltrate into the soil.

Geology and Hydrology

The terminal area is underlain by sands of Recent age which are probably former dune sands and beach sands. Bits of marine shells and partly fossilized wood are both present in the sands. Iron concretions are also present in the sand, but there is very little or no clay down to a depth of about 20 to 30 feet. At this depth there is a clay layer that separates the recent sands from much older marl and limestone below. Toward the river, clay layers become common at depths of 4 to 6 feet. This is interpreted to mean that the river is separated from the sands by clays deposited in the estuary contemporaneously with the sands.

In some areas there are also as many as 3 or 4 feet of man-made fill.

The water table is 1 to 15 feet below land surface and is therefore entirely in the Recent sands. The sand is quite permeable; pumping tests have indicated transmissivities of up to 12,000 gpd/ft. Within the terminal area the direction of groundwater movement is generally to the west, or

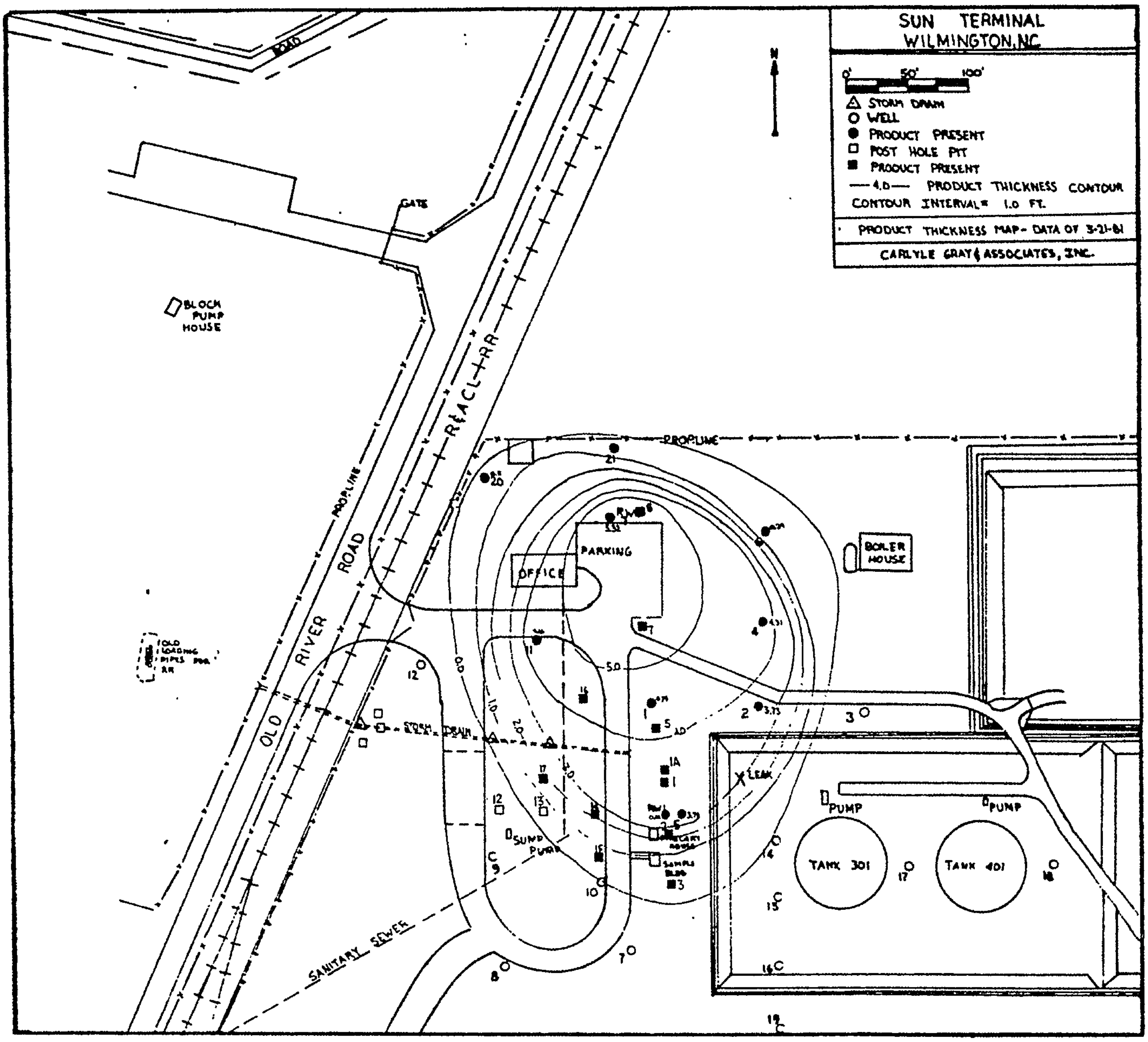

FIGURE 1: Wilmington Terminal and results of the initial exploration, March 21, 1981.

west-northwest, toward the Cape Fear River. West of the River Road the flow is slightly more northerly, toward a pond in the State Ports area that appears to be a local groundwater discharge area.

Although there is a tidal fluctuation of 5 to 6 feet in the Cape Fear River, no tidal fluctuation of the water table has been detected.

Spill History

In January of 1981 approximately 70,000 barrels (291,000 gallons) of paraxylene was lost through a leak in a pipeline during the unloading of a barge. The leak was later found to be in the pipeline at a point just inside the dike around tanks 301 and 401, see Figure 1 . The pipeline here is about 4 feet below the floor of the diked area. There are reports of an earlier, smaller spill, also of paraxylene, but none of this was ever definitely identified underground.

Later in the same month the fuel oil tank at the boiler room was overfilled and several hundred gallons were spilled into the dike around the fuel oil tank. Some of this seeped into the ground before the spill could be cleaned up.

It was first thought that the paraxylene spill in January of 1981 was relatively minor because there had been freeze-up problems during the unloading of the barge. However, a short time later, some paraxylene got into the sewer lateral running from the office to a sewer main located south of tanks #301 and #401. This paraxylene caused some damage to the sewer treatment system which made it evident that the leak was of major proportions. To prevent further damage to the sewer plant the sewer lateral was plugged.

My first visit to the site was on March 17, 1981. At that time the water table was very high and paraxylene was observed in the storm drain, which drains the area in front of the office, and in the the lagoon on the State Ports property. In order to start an investigation of the extent of the contaminated area a number of holes were dug by hand with a post hole auger (see Figure 1). These holes were 2 to 2.5 feet deep. They confirmed the presence of paraxylene in the area inside the oval road, as well as between the road and the dike behind which the leak occurred. It was decided that

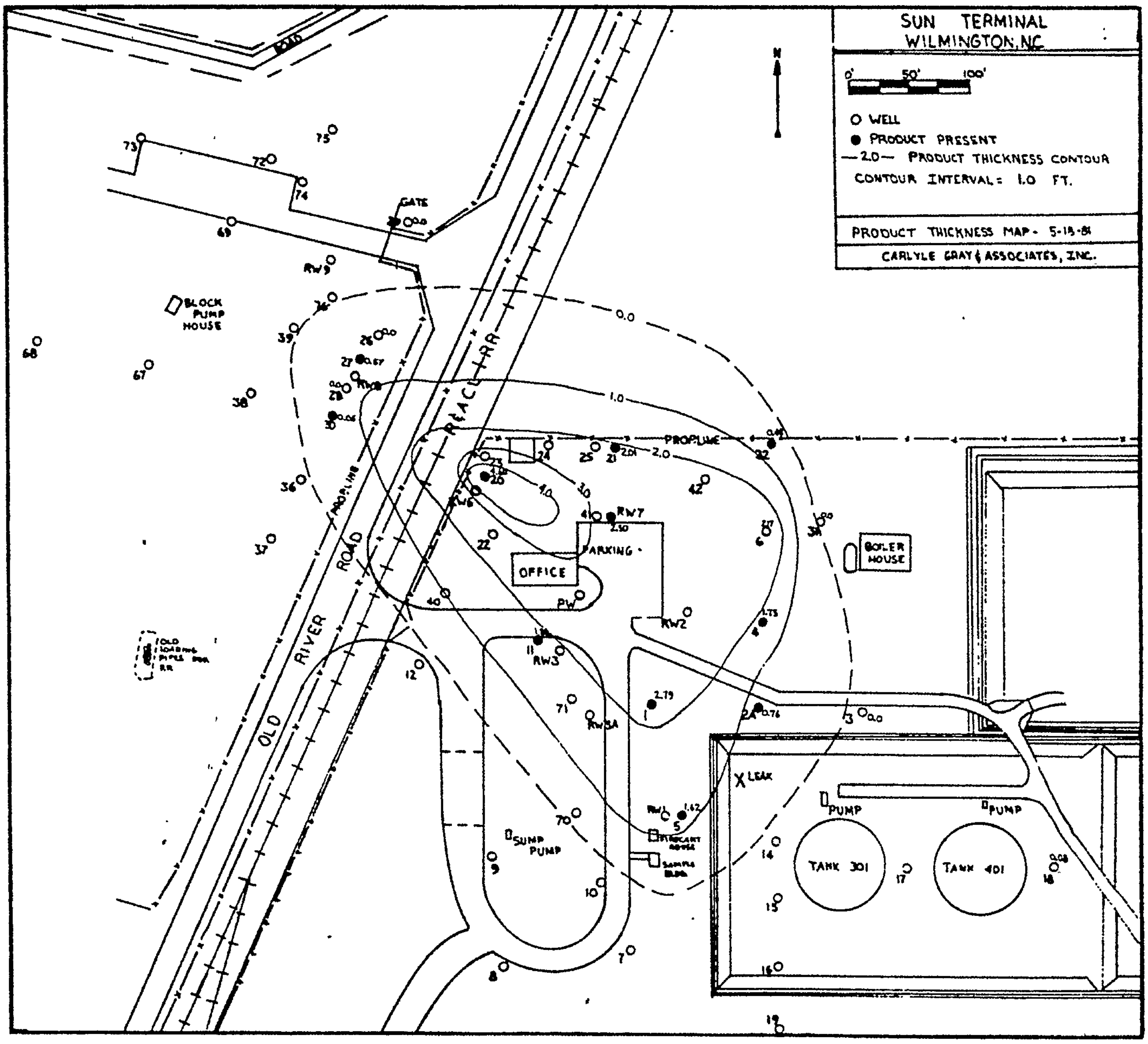

FIGURE 2: Product thickness on May 18, 1981, showing locations of the exploration holes on the State Ports property and along the north fence line of the Terminal.

further exploration and the installation of monitoring wells would be required.

On March 19-20, 1981, twenty-one exploration holes were drilled using an auger drill. The holes were screened and cased with 1.5 inch diameter P.V.C. slotted pipe. The holes were all drilled a minimum of 5 feet into the water table and were 13.5 to 19.5 feet deep. Figure 1 shows the extent of product as it appeared at the completion of this phase of exploration. Clean-up operations (see below) began immediately, and it was not until May 13, 1981, that exploration was extended.

By that time product had appeared in holes 20 and 21 and it was obvious that the paraxylene plume extended beyond the northern fence and also to the west under River Road. Because this last was in the direction of groundwater flow, it was considered essential to drill some holes on the State Ports property, west of River Road. Five holes (wells 26 - 30; see Figure 2) were drilled on May 13 and 14, 1981. Product odor was noted in all but one of the wells during drilling, but free product did not show up in the wells until later. Exploration on the State Ports property continued intermittently until September, 1982, when the limits of the down-gradient end of the plume were finally established.

In the Sun Terminal area, the wells within the contaminated area had up to 5 feet of paraxylene in them within a day of completion. In March of 1981 the thickest area of the plume was not at the leak point, but under the office.

Recovery Operations

The holes dug by auger drill on March 17, 1981, had shown that in the area immediately east of the dike enclosing tanks #301 and #401 the paraxylene was less than 2 feet below the land surface. It was decided that the first recovery well would be installed there at the same time that the drilled exploration holes were being installed. A 4 feet long section of 26 inch diameter bridge slotted steel (0.030 inch slot) screen with steel plate bottom was obtained from Handex in New Jersey. This was delivered, along with a Scavenger from the gasoline spill at Cedarhurst, New York, by an employee from Marine Pollution Control on March 3, 1981. A hole about 5 feet deep was dug with a back hoe, the screen was installed, and the hole immediately backfilled with clean, finely crushed limestone, about 0.25 inch in diameter. The gravel pack was a minimum of 1 foot thick. The top of the screen was about 6 inches below the original land surface. One hour after installation was completed the well had 1.5 feet of paraxylene in it. By this time it was evident that the product thickness in this area was going to be on the order of 5 feet. It was therefore decided to start recovery immediately with the Scavenger and to consider the problem of creating a cone of depression later. Recovery began immediately.

The initial twenty-one exploration holes showed that the greatest thickness of product was in the vicinity of the office. By March 25, 1981, it was decided to install three more recovery wells closer to the area of greatest product thickness, as indicated by the measurements in the recently completed observation holes. The depth to the top of liquid was slightly greater in that area, so the holes were planned to be 9 feet deep with 4 feet of screen (same size and type as in recovery well 1) and with 5 feet of blank pipe above the screen. The screens were delivered by March 3, 1981, and recovery wells 2, 3, and 4 were installed by backhoe that day. (See Figure 3.)

Recovery from well 1 was irregular at first, but averaged 475 gallons per day for the first ten days. Cold nights causing freeze-up of the paraxylene lines were the principal cause of irregular recovery at that time. After Scavengers were installed in all four recovery wells there continued to be periodic operational problems with the equipment. Because of this, continuous operation of more than two Scavengers at the same time was not achieved until nearly the end of April, yet through this period recovery averaged nearly 2,000 gallons per day.

After the recovery wells had been installed, our attention turned to the problem of creating a cone of depression. The high rates of recovery that we were achieving without depression pumps were possible because we were dealing with product thicknesses of 4 or 5 feet. Under these conditions, the Scavenger itself creates a small cone of depression and there can be substantial flow to the well. At the same time, however, the water-paraxylene interface mounds upward cutting off the lower part of the product mass from the recovery well, see Figures 4, 5, and 6. It was obvious that some kind of depression of the water table would have to

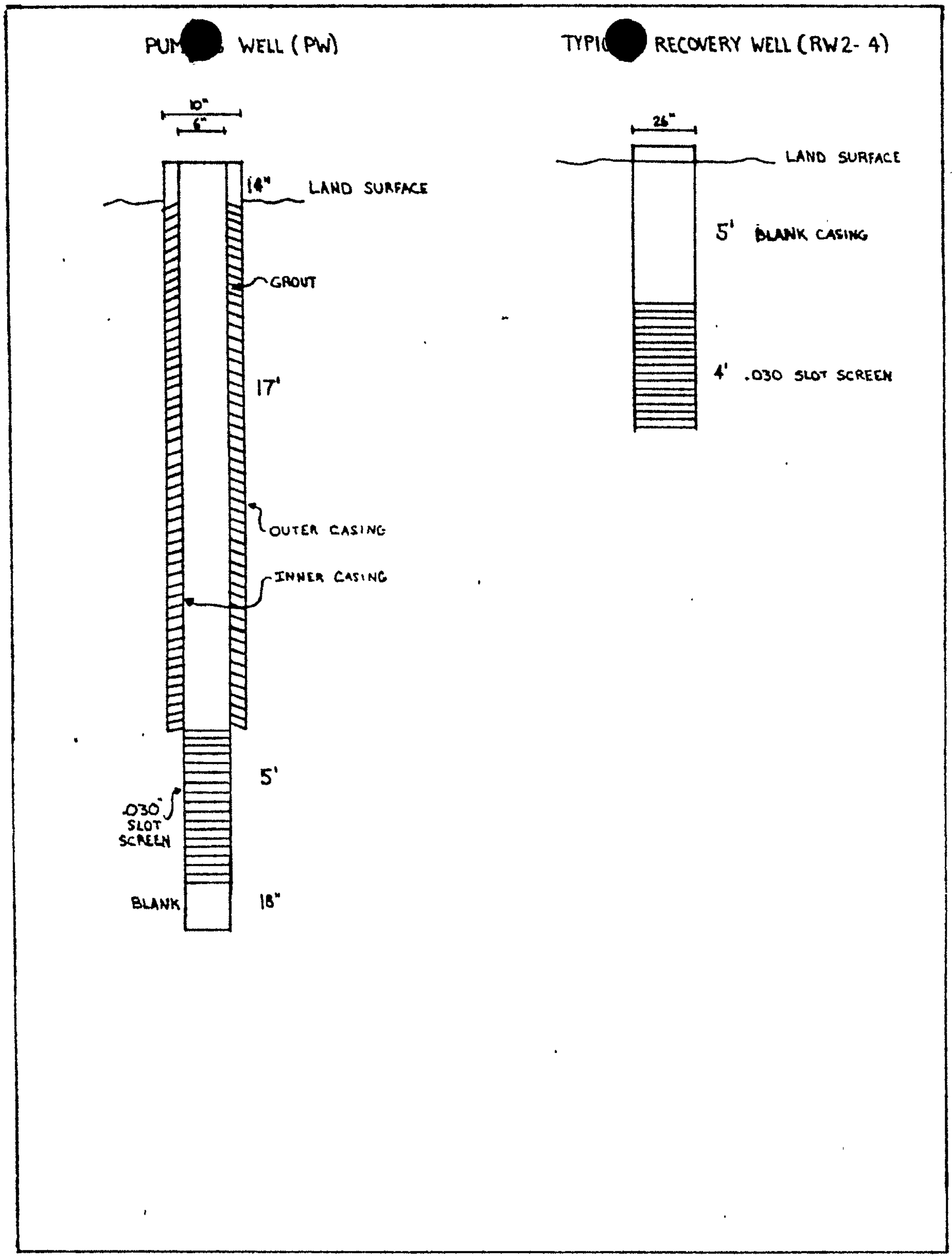

FIGURE 3: Construction of pumping well 1 and typical recovery wells.

be achieved to sustain the high recovery rate. In addition, by April 9, 1981, wells 20 and 21 near the edge of the Terminal area had developed substantial thicknesses of product, and it was obvious that the plume now reached beyond the edge of the Terminal area. It was considered urgent to create a large cone of depression to contain the product from further migration. It was decided, therefore, to install a deep water well near the center of the plume, in order to create a large cone of depression and prevent further product migration.

We had no detailed geologic information on the immediate vicinity but published reconnaissance reports indicated that the water table aquifer was limited at depth by the top of the Castlehayne Limestone, here 10 to 20 feet below sea level, or 40 to 50 feet below land surface. It was decided, therefore, to install a 6 inch diameter well, gravel packed, with 10 feet of screen in the lower part of the well. It was hoped that this well would yield enough water to create a cone of depression that would include most of the spill area.

The well was drilled on April 18, 1981, a time when I could not be present. A clay layer was encountered at a depth of 22 feet. It was decided that this was probably the base of the water table aquifer and there was no point in drilling deeper. The well was completed, therefore, with the casing program shown in Figure 3. Subsequent exploration has confirmed that this clay layer is indeed widespread in the area and that the correct decision was made.

Pumping tests were run on this well on April 21, 1981, and again on April 28 - 30, 1981. The well yield could never be sustained at greater than 5 gpm and the resulting cone of depression was too small to achieve its purpose. Other methods were then tried to contain the spill and increase recovery.

Recovery well 5 was installed along the west fence line of the Terminal just south of observation well 20 on April 30, 1981. Recovery well 5 consisted of 4 feet of screen plus 6.5 feet of casing. It was installed with a back hoe. Initially there was more than a foot of liquid in the well, but after the weekend there were only a few inches of water and product in the bottom of the well, not enough to float a Scavenger. On May 3, 1981, the depth to product in recovery well 5 was about 9 feet below the land surface, while only fifteen feet away the level in well 20 was only 6 feet below land surface. There

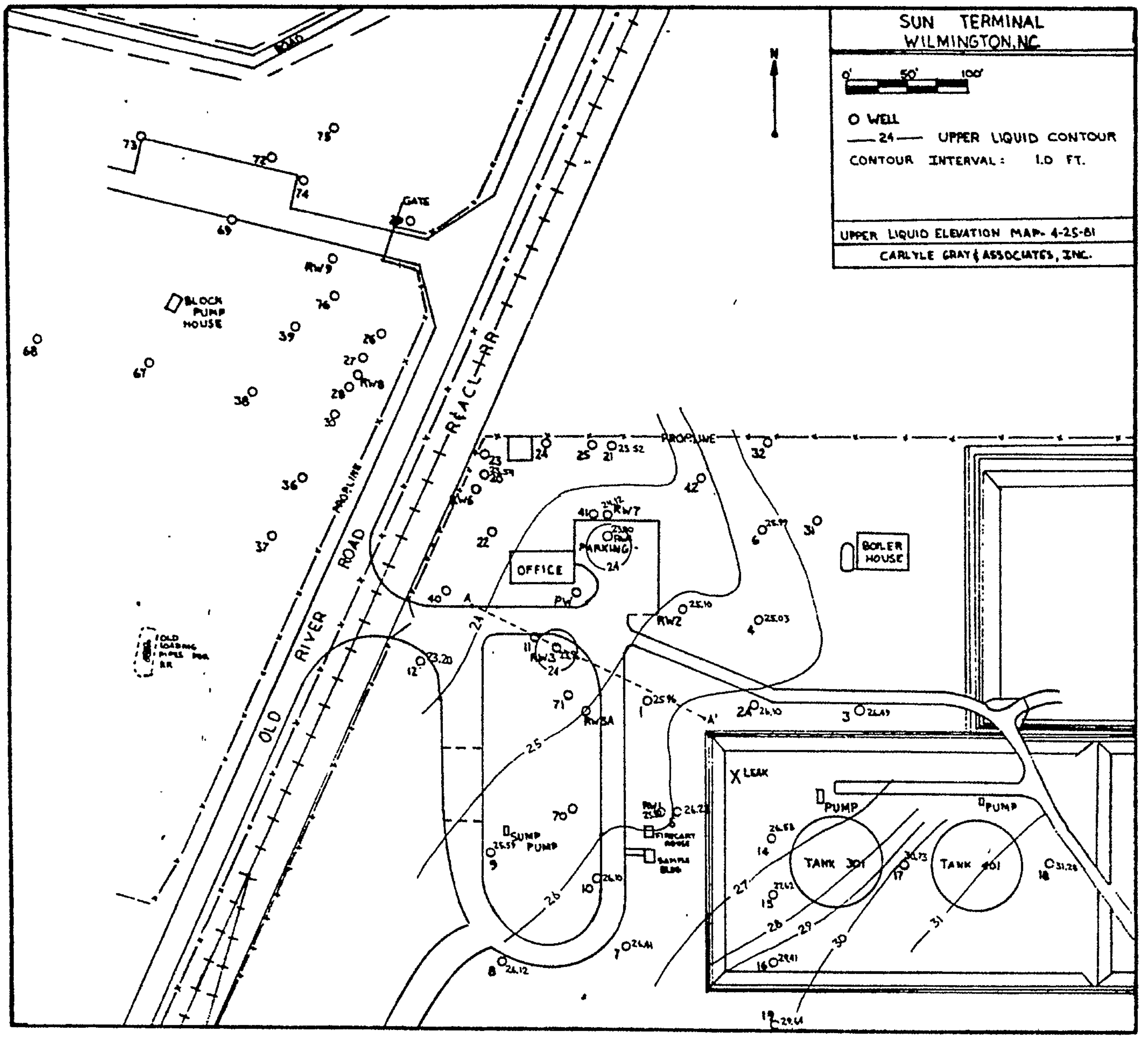

FIGURE 4: Top of liquid on April 25, 1981. Note the small cone of depression at the recovery wells.

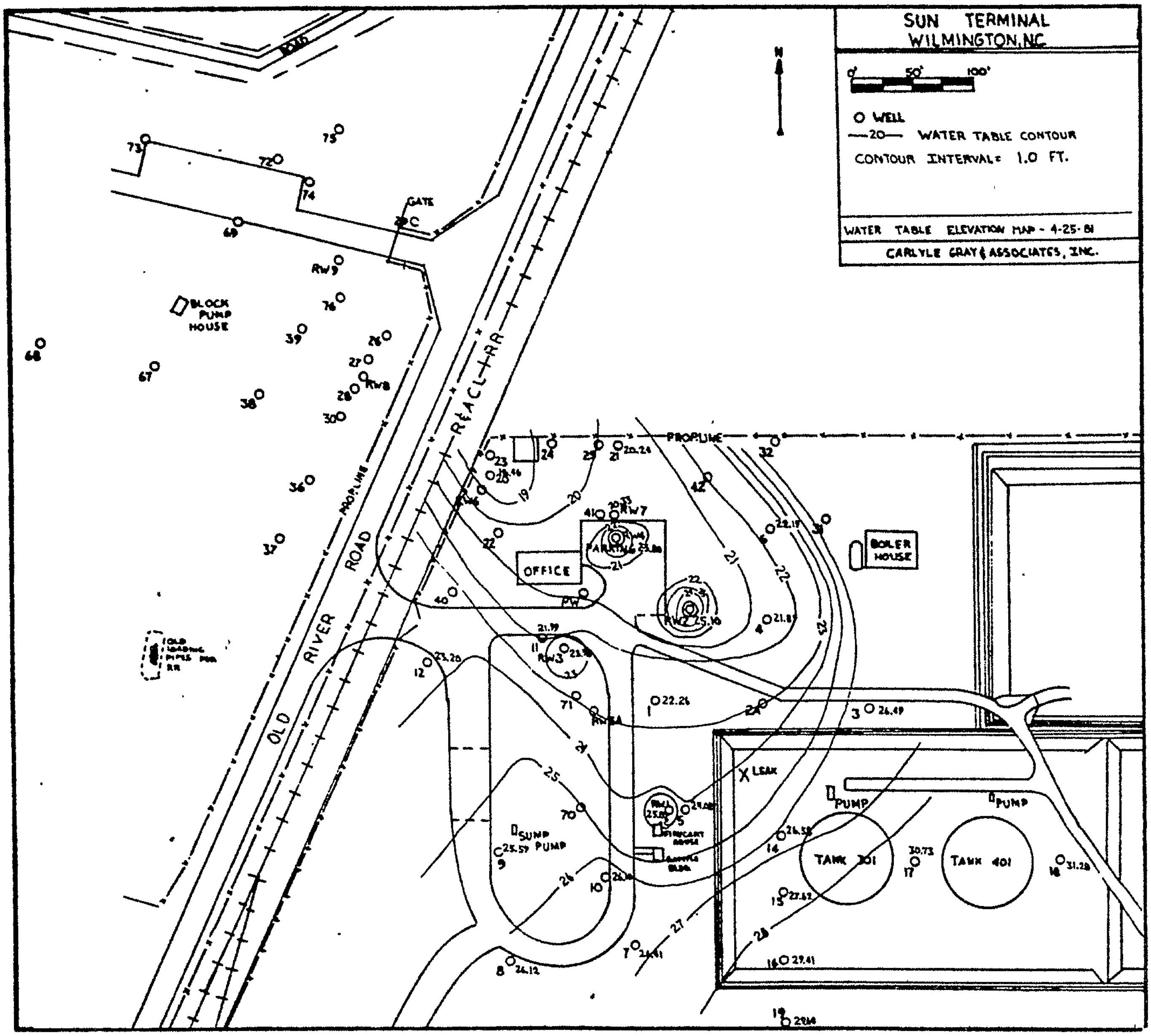

FIGURE 5: Top of water on April 25, 1981. Note the upward mounding of the water-paraxylene interface at the recovery wells.

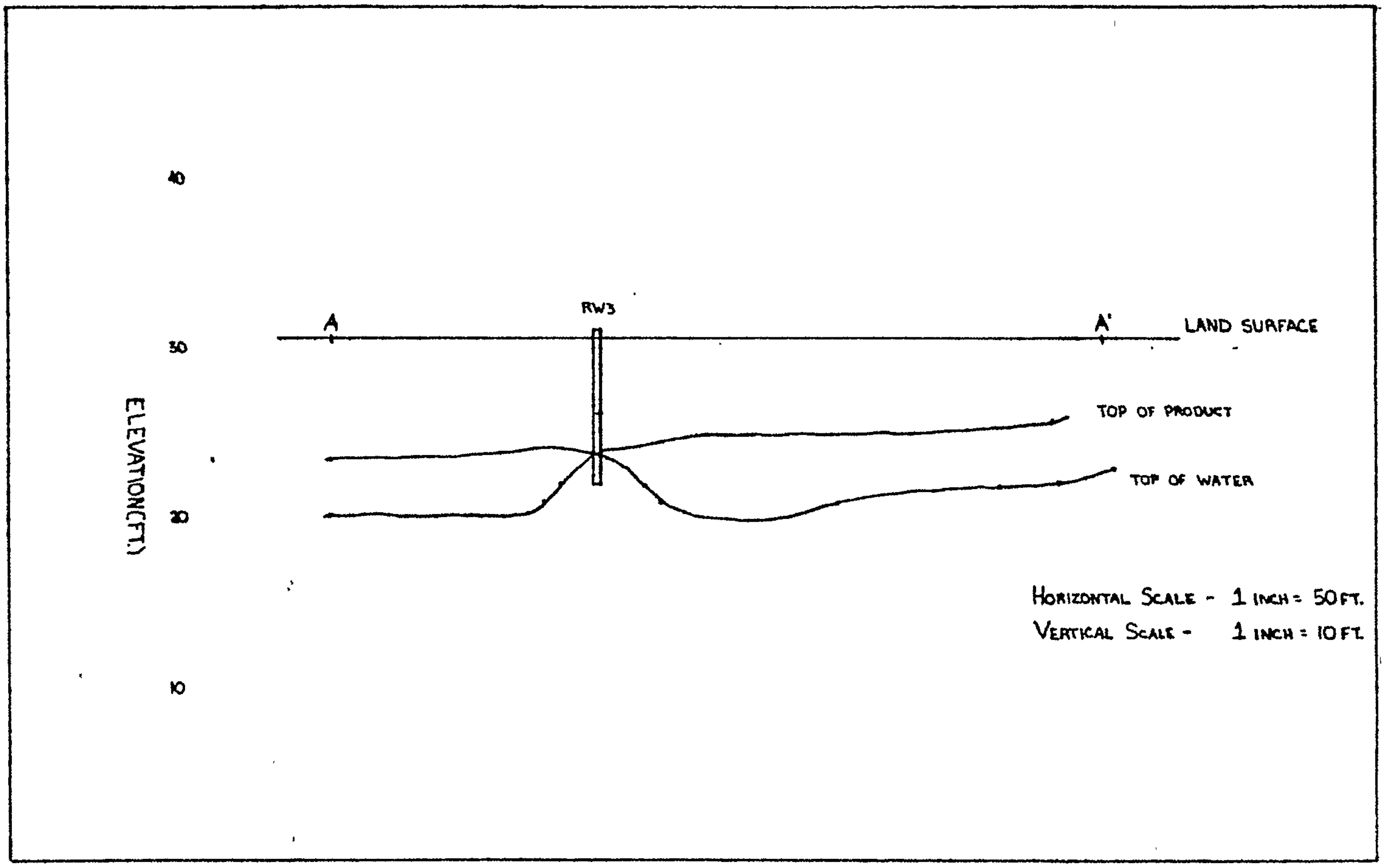

FIGURE 6: Cross section through recovery well 3 on April 25, 1981, to show the mounding of water and paraxylene.

is a perched condition in this area that we do not fully understand.

At the same time that recovery well 5 was installed, four well points (Wells 22, 23, 24, and 25) were installed in the northwest corner of the terminal. These are all 20 feet deep and each has 2.5 feet of screen at the bottom. It was our intention to pump water from these well points to prevent further migration of the product.

By May 15, 1981, it was clear that recovery well 5 was not deep enough to be effective at its first location. It was moved to a new location between well points 24 and 25 on May 20, 1981.

The well points were then attached to a pump to create a cone of depression around recovery well 5. This worked so well that by October, 1981, there no longer was any product north of the north boundary of the Terminal. (See Figures 7 and 8.)

In the meantime a deeper well, designated recovery well 6, was constructed for the original location of recovery well 5. This well consists of 12 feet of screen and 8 feet of casing, and was installed using a large diameter rotary drill during the last week in May of 1981. A scavenger was installed on June 10, 1981, but the depression pump was not effective initially. On July 23, 1981, the well was equipped with a submersible depression pump with automatic level control. Although recovery well 6 suffered many equipment problems through the fall and winter of 1981-82, in May of 1982 it was still the most successful recovery well.

When the depression pump in recovery well 6 was operating, its effect could be seen on product levels and thickness in the wells on State Ports property. (See Figure 9.) However, a positive slope toward recovery well 6 was never convincingly established and maintained. It was decided in August, 1981, that it would be necessary to install a recovery well west of River Road to complete the recovery program.

In July, 1981, well points were installed next to recovery wells 1, 2, and 3. It was felt that this substantially increased the recovery rate during the latter half of July. By mid-July, however, the Scavenger in recovery well 5 was resting on the bottom of the well, and we had to

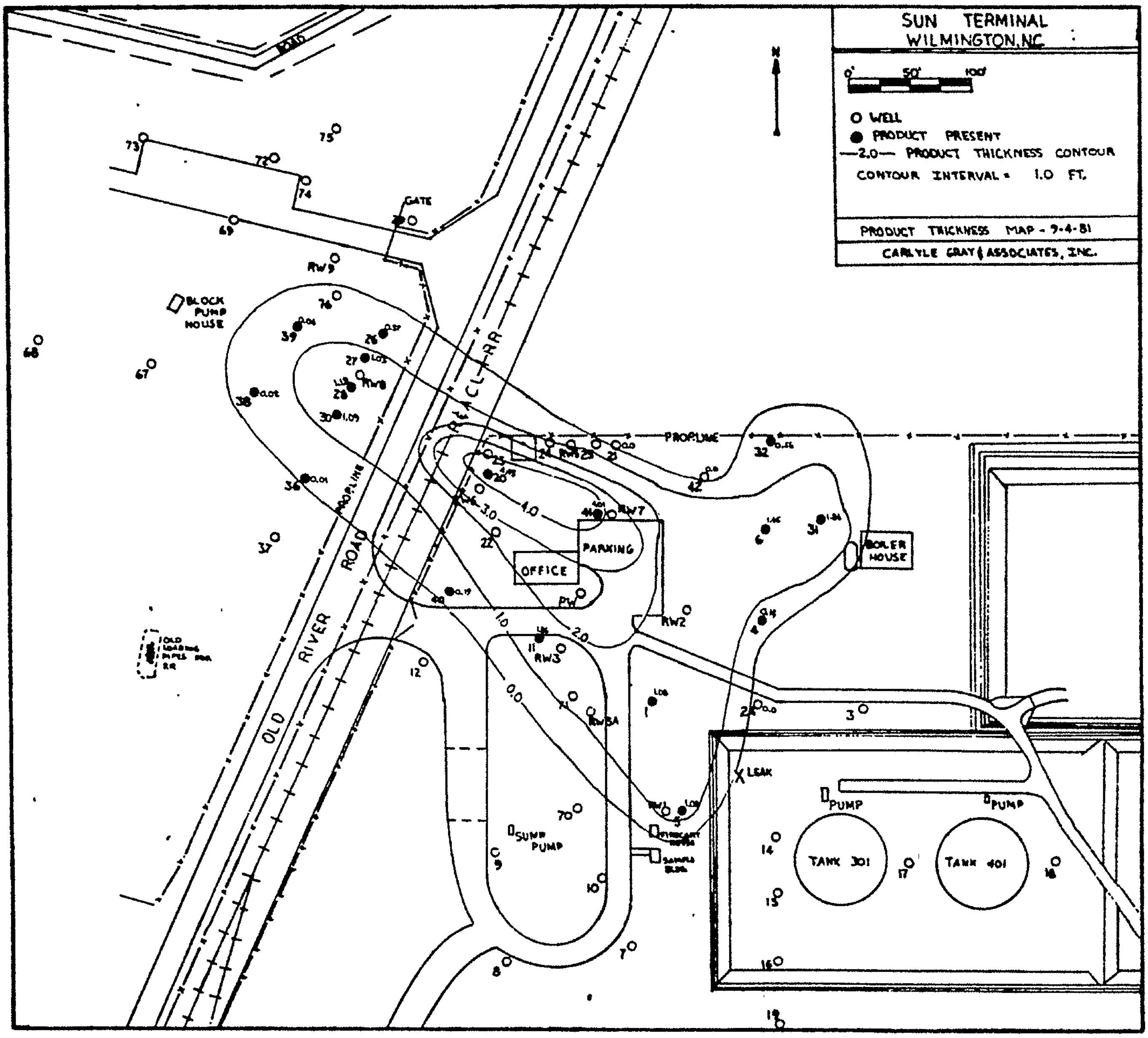

FIGURE 7: Product thickness on September 4, 1981. Compare with Figure 2 to see the effectiveness of recovery well 5 and, later, recovery well 7 in controlling the northward movement of paraxylene.

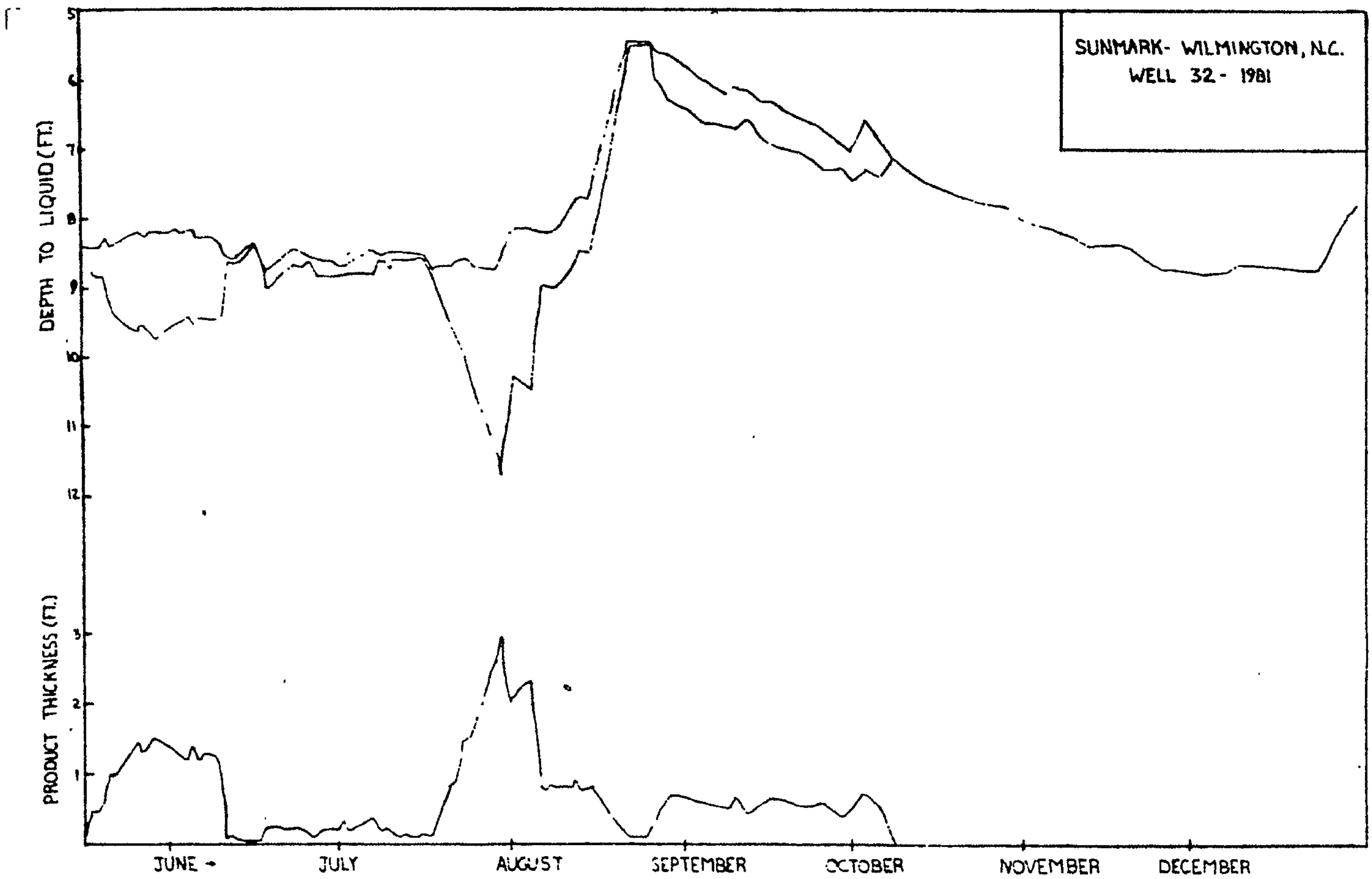

FIGURE 8: Hydrograph of observation well 32, along the north fence of the Terminal. The increase in thickness recorded in July was due to turning on the depression pump. All product was recovered from this area by October, 1981.

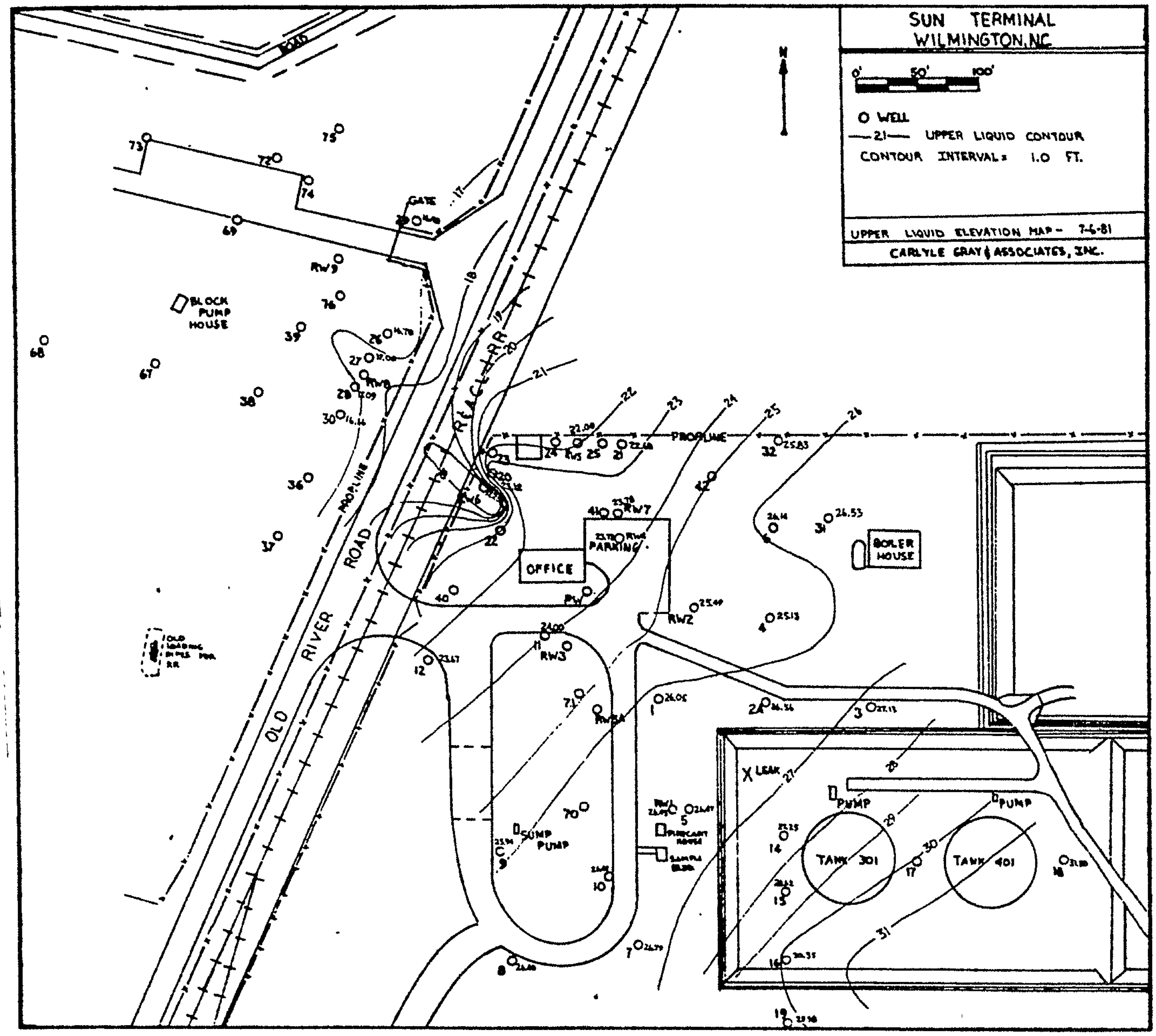

FIGURE 9: Upper liquid level on July 6, 1981. The depression pump in recovery well 6 was in operation.

turn off the well point nearby. By this time the recovery in well 4 had nearly ceased. It was decided, therefore, to pull the casings and screens from recovery wells 4 and 5, and combine them, making 8 feet of screen and 11 feet of casing for a total depth of 19 feet. This configuration was installed by rotary drill at the site of observation well 3 and became recovery well 7. Well points were installed next to the well for depression pumps. The well was completed and the Scavenger turned on by August 20, 1981.

For various reasons, including the gasoline spill at tank #5, recovery well 8 was not installed on State Ports land until October 1, 1981. Recovery began immediately. Initial rates of recovery were about 100 gpd. Increasingly cold nights slowed recovery until the system could be heat traced.

By the end of 1981 about 210,000 gallons of paraxylene had been recovered. Recovery was very slow during January and February of 1982 because of freeze-up problems. Drilling of additional observation wells in January, 1982, showed that the paraxylene plume extended beyond the cone of influence of recovery well 8 and that an additional well would be required. Because of ongoing construction on the State Ports property this well could not be located as close to the end of the plume as was desired. It was decided, therefore, to make the well as deep as possible to try to create a large cone of depression. Recovery well 9 was drilled with a rotary rig on February 9, 1982. It had been determined that the clay layer was at 20 feet at the location, so the well was equipped with 12 feet of screen and 8 feet of blank casing.

A three horsepower centrifugal pump was installed and began operating on February 17, 1982. Up to 8 feet of drawdown could be obtained with this pump. Automatic operation of the Scavenger was not possible until April, but the well was pumped off several times. At the end of May, 1982, there were problems with the water discharge and conflicts with the construction at the State Ports which were not fully corrected until September, at which time recovery operations resumed.

Recovery well 2 had ceased to recover product in October of 1981, and the screen and casing were pulled and used in the construction of recovery well 9. Recovery well 3 had ceased to recover by January, 1982, and it was moved on March 11, 1982, to be closer to a small patch of product which had become evident during the high groundwater levels in the winter.

Total recovery at the end of 1982 was about 238,500 gallons.

Recovery slowed even more in 1983 and essentially ceased by midsummer. (See Figure 10.) The final recovery was nearly 244,000 gallons.

Estimates of Paraxylene Volume

During the recovery operations frequent estimates of the paraxylene remaining to be recovered were made. Each estimate of the volume of paraxylene was based on maps of calculated thickness of saturated soil which had, in turn, been compiled from measurements of the thickness of paraxylene in the observation wells. For most maps, the thickness is contoured in one foot increments, and the area between two contours is measured using a planimeter (see Figures 11 through 16). The volume of saturated soil is calculated as this area times one-half the contour interval; the total volume is the sum of the volumes calculated for each contour interval. This gross volume does not represent the volume of paraxylene, however, because the paraxylene occupies only part of the pore space within the sand. The porosity of the sand is approximately 20%, as indicated by the pumping test results. Before the spill, this volume of pore space below the water table was entirely occupied by water. We estimate that the effective porosity of the sand to paraxylene, or the volume of the sand occupied by the paraxylene (both above and below the water table) is 10%. This effective porosity was calculated using the assumption that the number of gallons of paraxylene recovered within a specific time period is directly related to the decrease in the thickness of paraxylene noted in the observation wells over that same time period. If this decrease in thickness represents the same number of gallons of paraxylene as that recovered, and the area associated with the thickness change is also known, then the volume of sand occupied by paraxylene can easily be determined. The 10% effective porosity figure used here is based on measurements Of paraxylene thickness from April 9 to July 2, 1981. With this figure of 10% effective porosity, paraxylene volumes can be calculated using contour maps based on one set of observation well data.

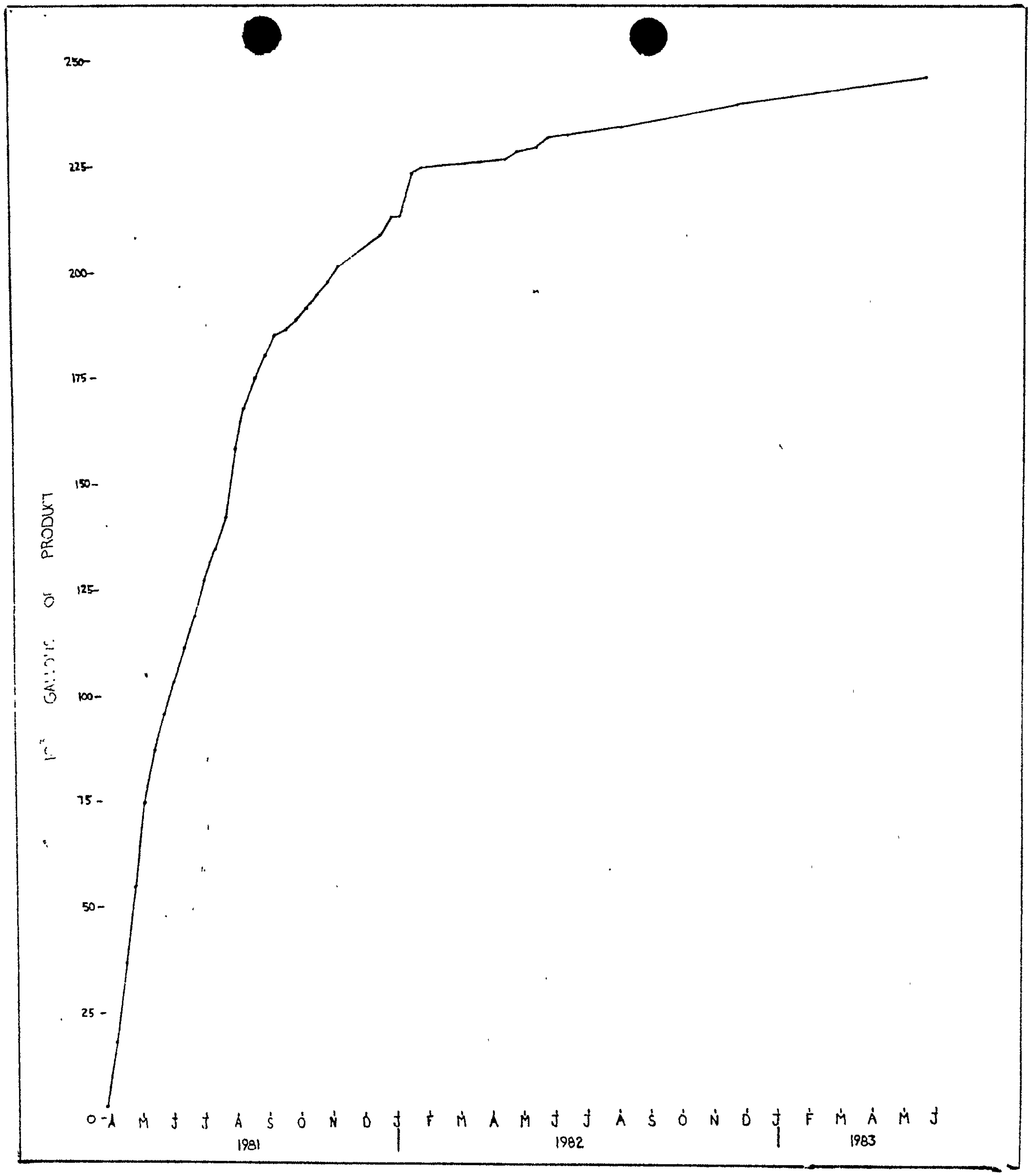

FIGURE 10: Cumulative recovery of paraxylene - 1981 to 1983.

Table I is a tabulation of estimates of paraxylene volumes made using this method and covering the period from May, 1981, to June, 1983. All have been calculated on the basis of 10% effective porosity of the sand to paraxylene. In order to make the estimates comparable, the amount of paraxylene recovered to date has been added to each estimate of product remaining in the ground. A total of 23 estimates were made and the total volume of paraxylene varied from 231,697 gallons to 346,860 gallons. This variation is due to a number of factors, among them precipitation, an over-accumulation of product in the observation wells, and variation in the total number of available observation wells. The average of these estimates is 283,429 ± 28,107 gallons.

TABLE I: PARAXYLENE VOLUME ESTIMATES AND RECOVERY

Date	West of R.R.	East of R.R.	Total	Recovery to Date	Grand Total
5/18/81			155,674	90,000	245,674
6/4/81			128,469	103,228	231,697
6/18/81			182,863	115,000	297,883
7/2/81			142,698	122,000	264,698
7/10/81			130,914	120,000	260,914
7/20/81			160,402	138,000	298,402
7/29/81			196,860	120,000	346,860
8/7/81			147,801	159,500	307,301
8/14/81	87,182	56,408	143,590	165,500	309,090
9/4/81			97,624	179,500	277,124
9/16/81	19,625	91,319	110,944	185,000	295,944
10/1/81			75,446	188,500	263,946
10/14/81			63,350	191,000	254,350
11/9/81	53,010	42,957	95,967	198,000	293,967
11/24/81	38,068	50,020	88,088	205,000	293,088
12/23/81	95,881	41,722	137,603	207,500	345,103
1/11/82	53,875	19,063	73,478	213,167	286,665
1/21/82	50,612	27,753	78,365	214,000±	292,365
3/22/82	26,231	29,378	55,609	223,820	279,429
5/19/82	23,244	14,231	37,475	228,527	266,002
11/3/82	10,203	14,952	25,155	234,294	259,449
12/13/82	20,893	3,968	24,863	240,623	265,486
10/17/82				243,609	

Taking another approach, four estimates were selected for the dates November 9 and 24, 1981, and January 11 and 21, 1982. On these dates the spill was fully outlined. The average of these four estimates in 291,521 ± 2,860 gallons.

If these estimates are correct, an earlier spill has probably not been encountered or recovered. There are at least two possible explanations for this: first, that the volume estimate is too small, and second, that the earlier spill had moved on past the area before the observation wells were completed. As to the first possibility, it must be noted that a small increase in the effective porosity - from 10% to 12%, for example - would greatly increase the total quantity of paraxylene originally present. In that case, an earlier spill could have been overlooked in the above calculations. The following section shows that the second possibility is also very real, since the rate of movement is large enough for the entire 30,000 gallons to have moved beyond the area of investigation.

Rate of Movement

The data collected during the cleanup of the spill is complete enough to make some rough estimates of the rate at which the product moved. Several of the holes that were drilled as observation wells did not show measurable product at the time they were drilled, but became contaminated later. The following table lists these holes, the number of days after the spill that they became contaminated, their distance from the point of the leak, and the calculated average rate of movement of the paraxylene.

well no.	date contaminated	days after the leak	distance	rate ft/day
sanitary sewer	2/26/81	39	150	3.8
21	3/28/81	67	290	4.3
20	3/20/81	59	320	5.4
28	5/27/81	127	450	3.5
38	8/18/81	210	510	2.4
39	8/20/81	212	520	2.4
74	2/1/82	376	600	1.5

The table indicates a fairly regular decrease in the rate of movement as the spill moved away from the point of the leak. There are several factors which may have contributed to this. The slope of the water table is greatest near the leak. This is intensified by the fact that the mounding of the spilled paraxylene increased the slope in the vicinity of the spill, particularly at first, and this effect would decrease with time after and distance from the spill.

Comparison with the rates of groundwater movement in this area shows that the product essentially is carried along by the underground water. The most reliable pump test data that we have indicate that the transmissivity of the formation is about 11,000 gallons per foot per day. Converting this to permeability (K), assuming the effective thickness of the aquifer to be 20 feet, K = 550 gal/day/square foot . Expressed as a velocity, this is 73 feet per day at 1:1 slope. The slopes measured on Figure 4 vary from a minimum of 0.012:1 under the parking lot to 0.05:1 just east of the leak. Groundwater flow rates therefore are from 0.8 to 3.7 feet per day, the same order of magnitude as the movement of the spill.

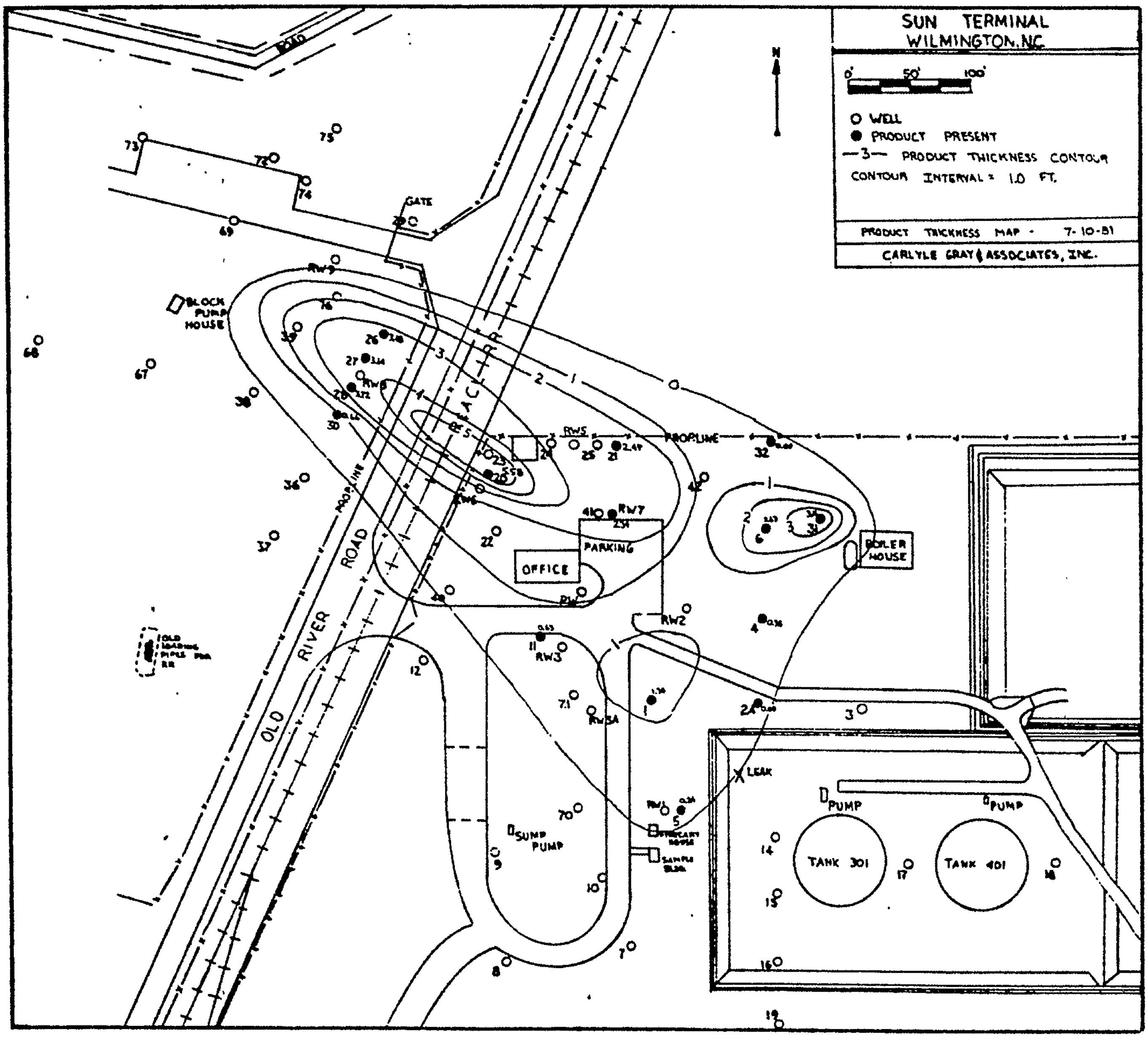

FIGURE 11: Known extent of paraxylene on July 10, 1981.

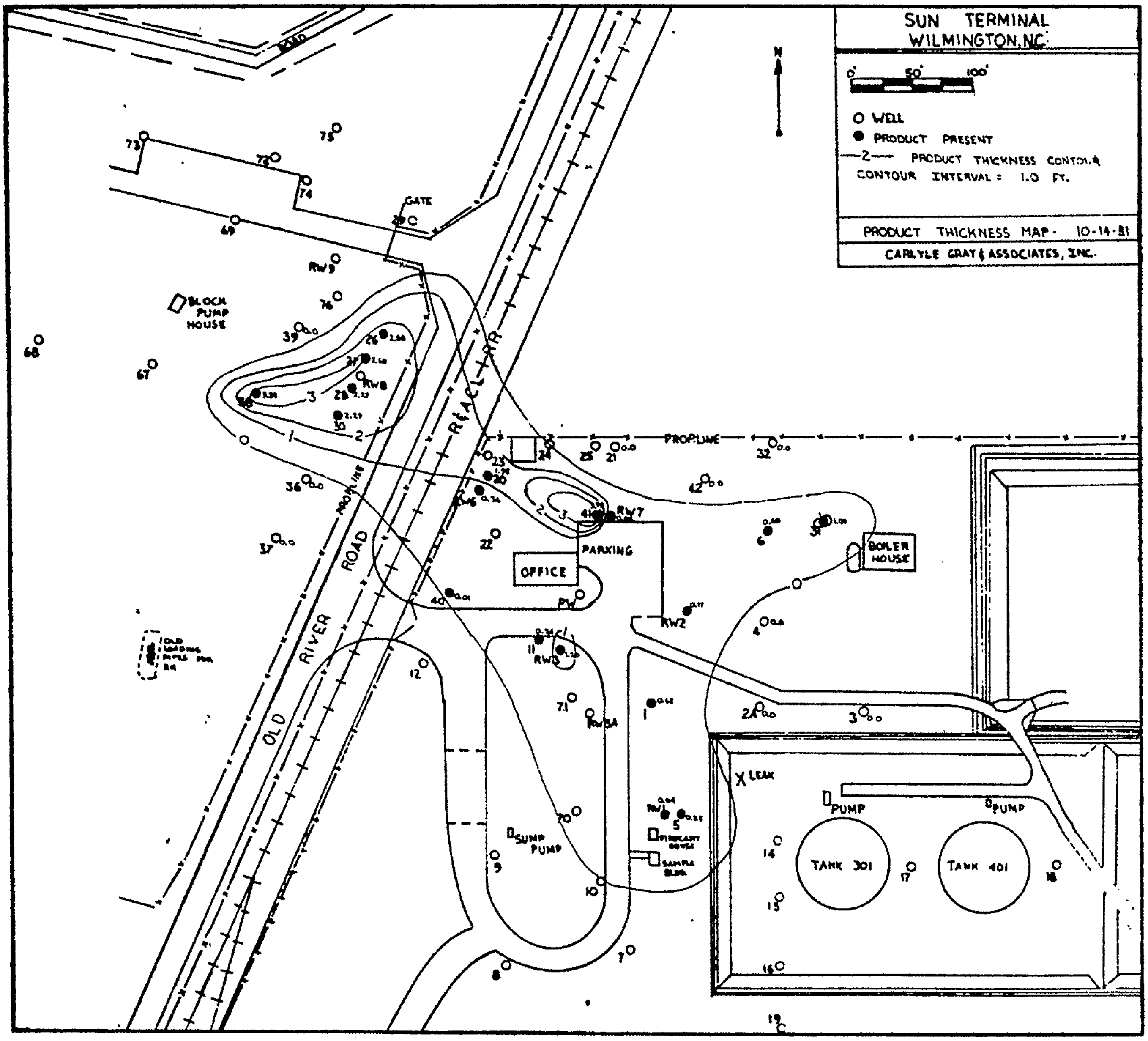

FIGURE 12: Extent of paraxylene on October 14, 1981. Note the reduction of the plume along the north fence of the Terminal and in the area of observation well 4.

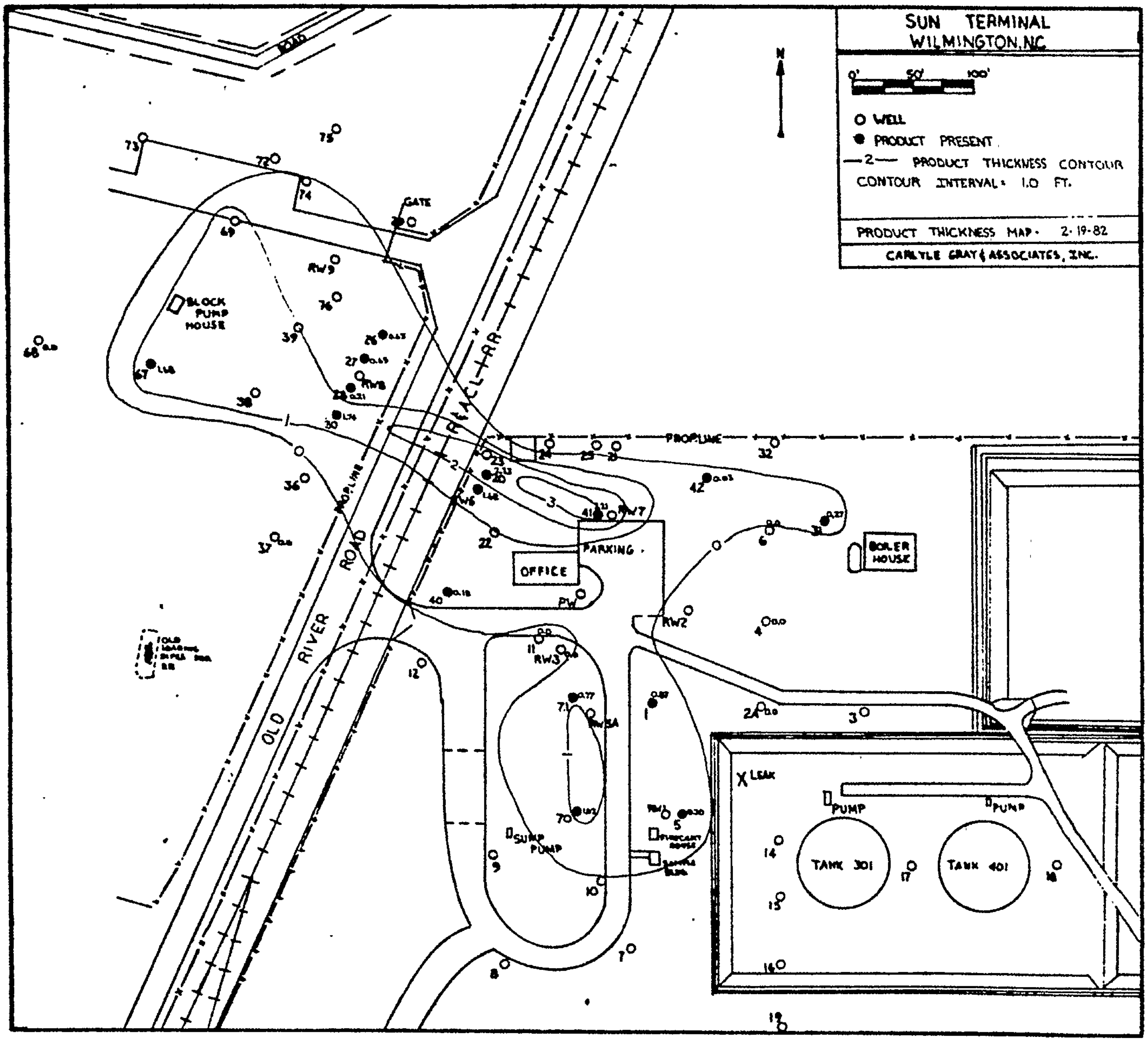

FIGURE 13: Extent of paraxylene on February 19, 1982. Note that recovery wells 2 and 3 no longer contain paraxylene.

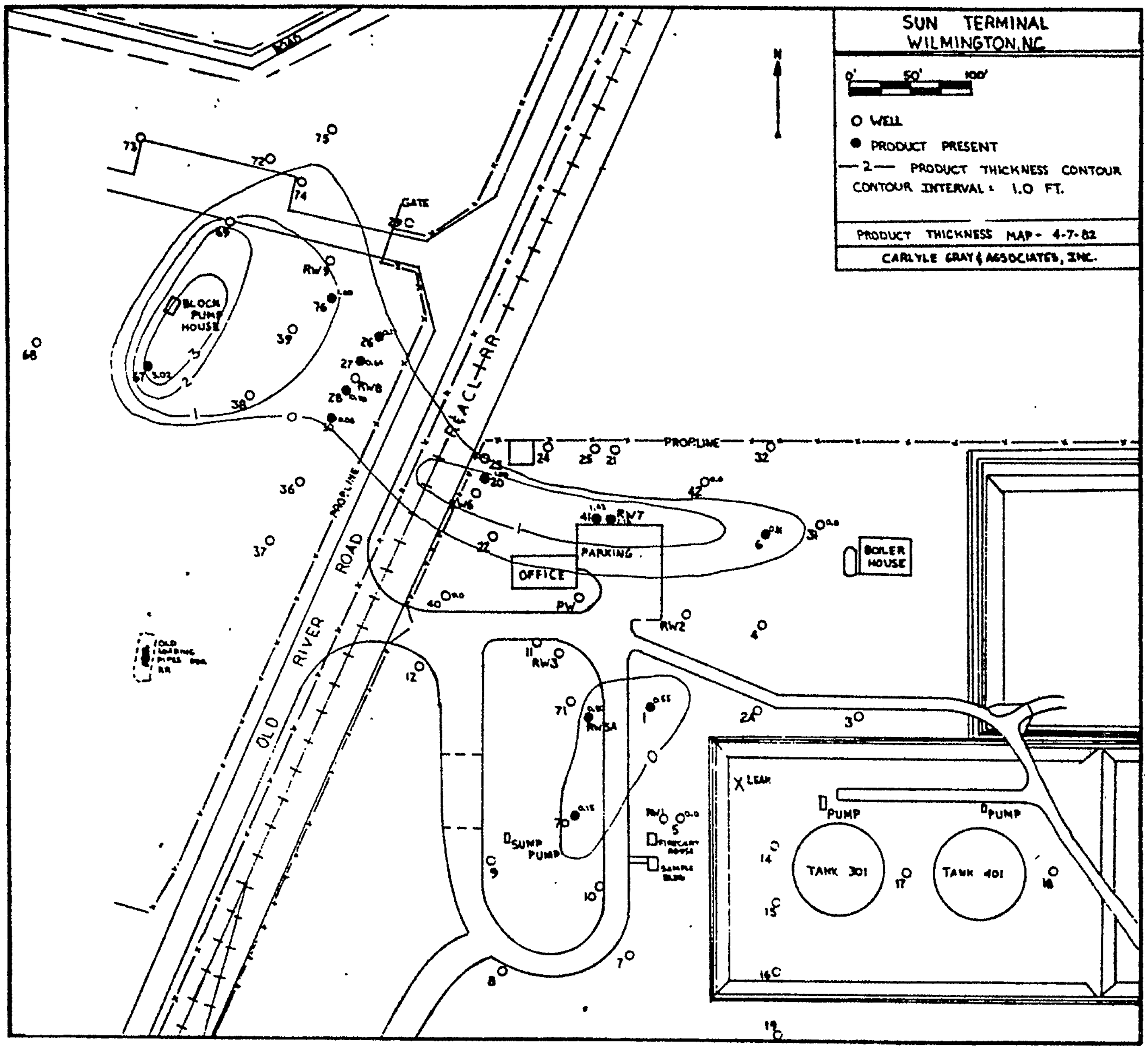

FIGURE 14: Extent of paraxylene on April 7, 1982. The product around recovery well 3A is now isolated from the main plume. In addition, the plume has extended to observation well 74.

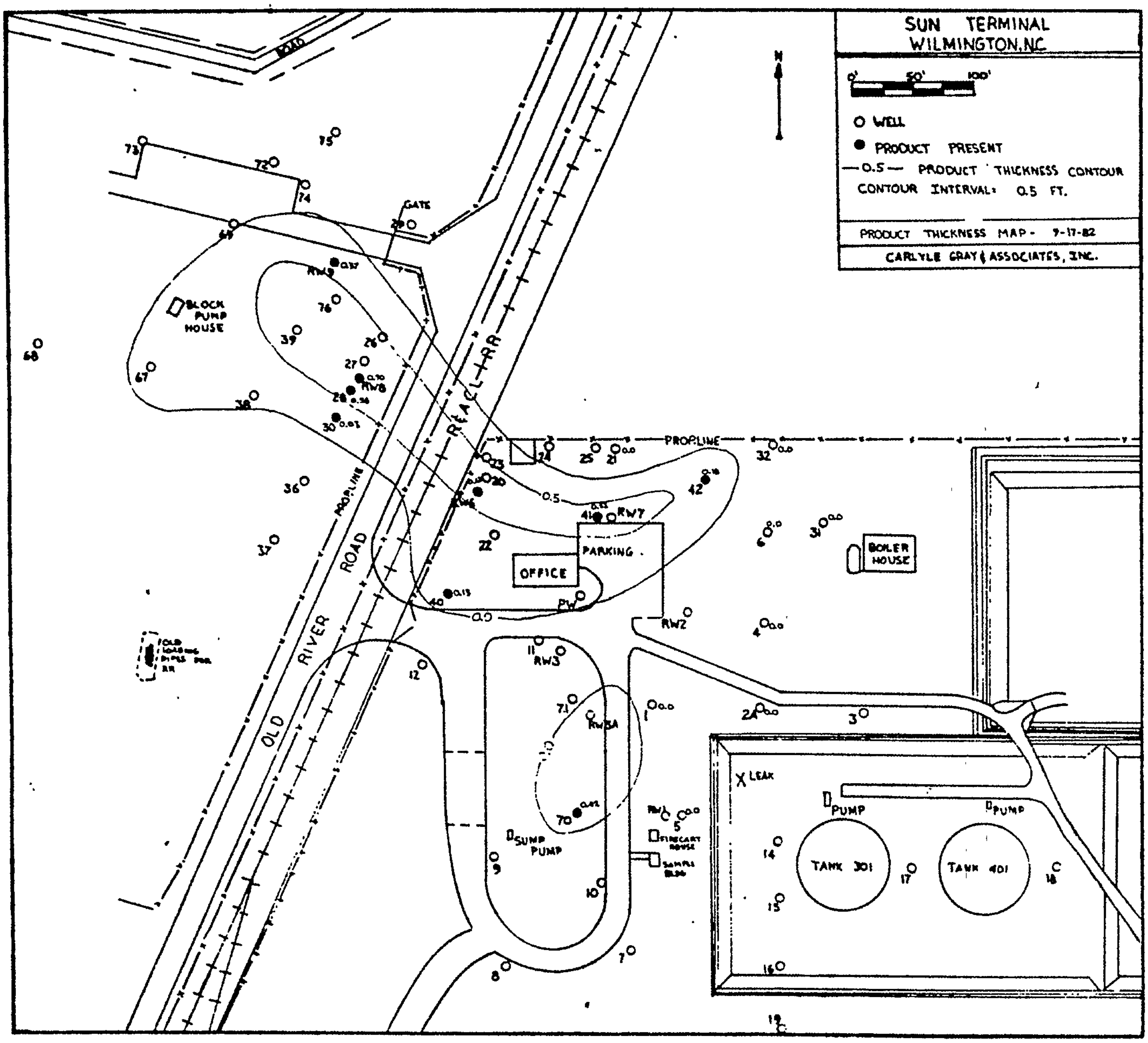

FIGURE 15: Extent of paraxylene on September 17, 1982. Pumping of recovery well 9 has pulled product back from well 74.

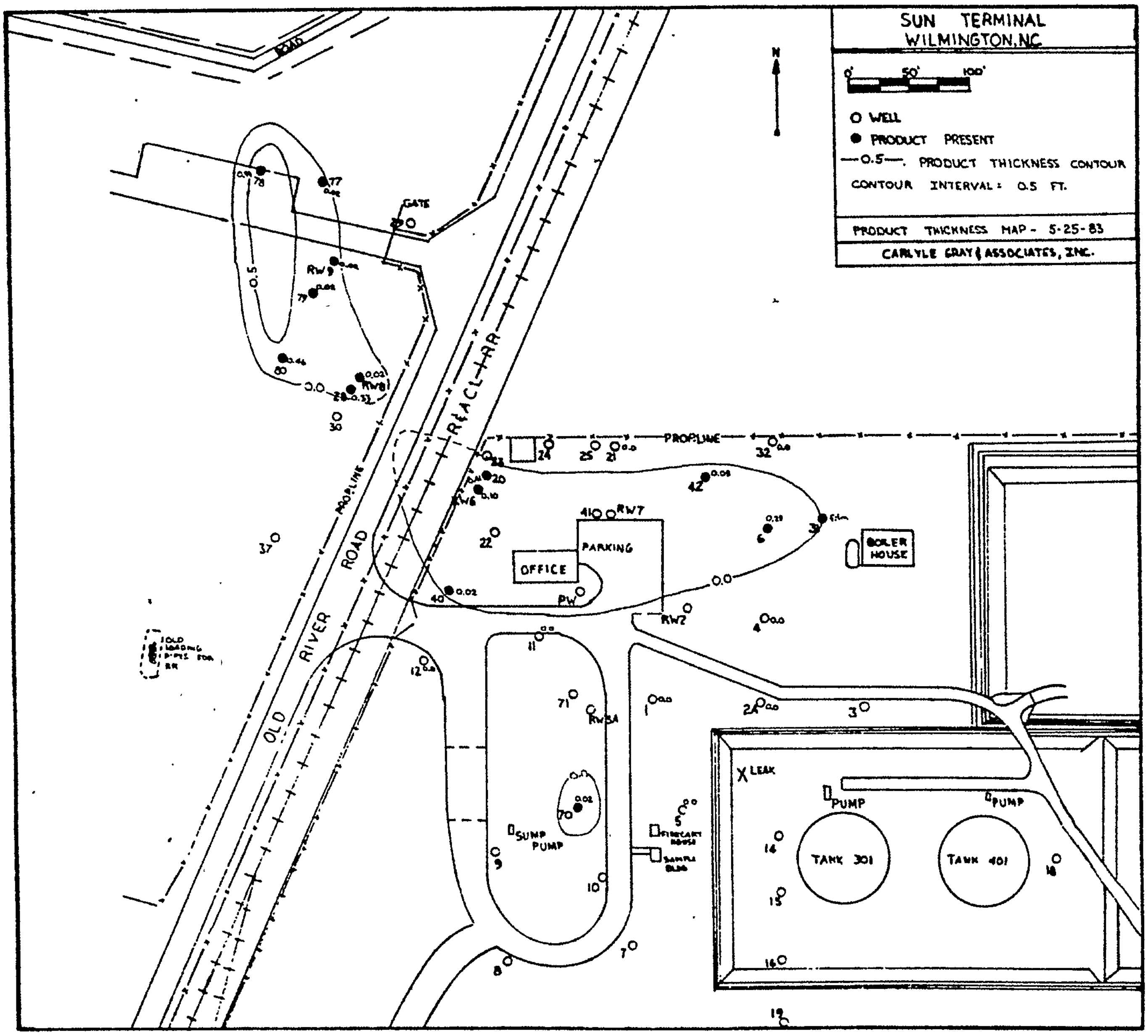

FIGURE 16: Extent of paraxylene on May 25, 1983. The plume now appears to be in three parts with the only significant amount left in the area of observation well 78.

Discussion of Effectiveness of Cleanup Activities

It is our belief that the cleanup of the spill by means of recovery wells has been as complete as is practicable. The series of Figures 11 through 16 shows how the mass of paraxylene in the terminal area gradually got thinner, then split into two parts, finally leaving just one small lens-shaped mass in the vicinity of recovery wells 6 and 7. The cleanup is not complete and from time to time small amounts of product show up in some of the observation wells, but the history of recovery in 1983 shows that these small amounts cannot be moved to the recovery wells.

Across River Road in the State Ports property the cleanup has not been quite so complete, but we feel confident that as much has been done as possible, given the construction activities at the Ports. The area around recovery well 8 is essentially free of paraxylene. Recovery well 8 has not had any product in it since late August, 1983. The remaining observation wells nearby have shown only fractions of an inch since then. There may have been some product remaining in the vicinity of well 67 but this is now under the freight container storage area. It is at most a small patch similar to that around recovery well 6. The largest remaining mass of product is in the area near recovery well 9 and observation wells 79 and 80. We believe that some of this may be recoverable, and for this reason the pump has been left in place and will be turned on again when warm weather returns.

January 23, 1984

Carlyle Gray