

SAMPLING INVESTIGATION RESULTS
LITTLE HOCKING WATER
ASSOCIATION WELL FIELD
WASHINGTON COUNTY, OHIO

Date: April 2003

Project No.: 7482
18983762.00010



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EXECUTIVE SUMMARY

DuPont conducted a field investigation of the Little Hocking Water Association well field in August 2002 in order to delineate ammonium perfluorooctanoate (C-8) concentrations in soil and groundwater near a test well, TW-4. Groundwater sampled from TW-4 in 2002 showed a C-8 concentration range of 12.3 to 37.1 ug/L. This report summarizes the work performed, presents results, and provides conclusions and recommendations.

Recently, pursuant to a multi-media consent order issued by the West Virginia Departments of Environmental Protection and Health and Human Resources to DuPont on November 15, 2001 (Order No. GWR-2001-019; Consent Order), DuPont had submitted summary reports to the Ohio Environmental Protection Agency detailing the off-site investigation activities near the Washington Works facility. These reports assessed media-specific C-8 transport from the facility and concluded that migration of air emissions is the only probable transport mechanism for C-8 found in the Little Hocking Water Association well field.

The field investigation of the Little Hocking Water Association well field focused on delineating depth-specific C-8 concentrations in soil and groundwater near TW-4. Concurrently, additional geoprobe borings, test wells and production wells were sampled in order to develop a site conceptual model for deposition and migration of C-8 in soil and groundwater at the Little Hocking Water Association well field. The following conclusions are drawn from the investigation results and other available data:

- ❑ All groundwater results are below the C-8 Assessment of Toxicity Team (CATT) established human health protective screening criteria for water (water C-8 SL; WVDEP 2002) of 150 ug/L.
- ❑ The C-8 concentrations in groundwater decreased with depth within the aquifer. The C-8 concentrations in groundwater at the top of the aquifer, within the silty clay, ranged from ND (<0.01 ug/L) to 78 ug/L, while C-8 concentrations at the bottom of the aquifer, within the sand and gravel, ranged from ND (<0.01 ug/L) to 8.58 ug/L (excluding results for TW-4).
- ❑ Consistently high pH values measured in TW-4 and other field observations indicate that this test well's construction is likely compromised, possibly due to a failed grout seal or to a failed well casing. Higher concentrations of C-8 measured in this well (ranging from 12.3 to 37.1 ug/L) are likely attributed to shallow groundwater that contains higher C-8 concentrations migrating downward into the deeper monitoring zone or into the well itself, which could happen if the grout seal or the well casing were to have failed. C-8 concentrations measured in this well are not likely to be truly representative of the deep aquifer.
- ❑ Drinking water is pumped from the bottom of the sand and gravel aquifer through the four production wells. The highest C-8 concentration measured in the four production wells was 8.58 ug/L, significantly lower than the human health protective water C-8 SL. The C-8 results for finished water, a combination of

waters from the production wells that is distributed to Little Hocking customers, ranged from 1.69 to 4.29 ug/L, also significantly lower than the water C-8 SL.

- ❑ All soil results are below the CATT-established human health protective screening criteria for soil (soil C-8 SL) of 240 mg/kg (WVDEP 2002). The highest soil C-8 concentration measured is 170 ug/kg (0.170 mg/kg). Most results for soil sampled below the water table are nondetectable.
- ❑ Overall, the very low concentrations of C-8 measured in the soils indicate that C-8 does not readily adsorb to soil, especially soils below the water table.
- ❑ C-8 results for soil and groundwater sampled immediately adjacent to TW-4 do not distinguish this test well as a source for higher C-8 concentrations in soil and groundwater.
- ❑ Overall, this investigation as completed, combined with the air emission modeling and groundwater modeling results and the available physiochemical data for C-8, are sufficient to understand the migration pathways of C-8 from the Washington Works facility and within the Little Hocking Water Association well field.
- ❑ Revised groundwater modeling by DuPont supports the previous conclusion that no potential groundwater migration pathway exists beneath the Ohio River to the Little Hocking Well field.
- ❑ Based on the current data available, DuPont believes the following pathway does exist. C-8 from the DuPont facility is transported via air emissions by wind and is deposited on the Little Hocking well field surface soils. Precipitation then leaches the C-8 downward through the unsaturated zone to the aquifer. Dissolved C-8 then migrates with groundwater within the aquifer. Groundwater containing low levels of C-8 is then pumped from the aquifer through the four production wells. Water from the production wells is mixed and the finished water, containing even lower levels of C-8, then enters the Little Hocking Water Association distribution system.
- ❑ This investigation as completed, combined with the overall understanding of C-8 migration pathways within the Little Hocking well field, is also sufficient to understand the distribution of C-8 in the test wells, including TW-4, in the production wells and in the finished water that enters the Little Hocking distribution system.
- ❑ In order to assess the impact of recent C-8 air emission reductions at the Washington Works facility, DuPont recommends continuing quarterly monitoring of C-8 in the four Little Hocking Water Association production wells and finished water for a period of two years.

1.0 INTRODUCTION

Pursuant to the multi-media consent order issued to DuPont on November 15, 2001 (Order No. GWR-2001-019; Consent Order), groundwater was sampled at public water supplies (PWS) along the Ohio River in West Virginia and Ohio. Groundwater was sampled to determine if releases of C-8 from the DuPont Washington Works facility (located in Washington, West Virginia) have impacted groundwater in the PWS. The PWS sampling was performed under the direction of the Groundwater Investigation Steering Team (GIST) which was established under the Consent Order. The Little Hocking Water Association well field, located across the Ohio River from the Washington Works facility in Washington County, Ohio, was included in this sampling. The locations of the Little Hocking Water Association well field and the DuPont Washington Works facility are shown in Figure 1.

Four production wells at the Little Hocking Water Association well field (LHPSD1 through 4) were sampled in December 2001. The C-8 concentrations measured in the production wells ranged from 0.844 to 7.66 ug/L. To better understand the distribution of C-8 in the Little Hocking well field, a more extensive sampling event was conducted in January 2002, that included the sampling of finished water (the water distributed to customers) and booster station sampling points, and groundwater from all production and test wells in the well field. The locations of the production and test wells sampled in the Little Hocking well field are shown in Figure 2.

A total of 19 groundwater samples, including one duplicate, were collected and analyzed from Little Hocking during the January 2002 sampling event. The concentrations of C-8 in finished water and booster station sampling points ranged from 1.69 to 1.94 ug/L. The C-8 concentrations measured for the production wells ranged from 0.744 to 6.22 ug/L. The C-8 results for nine of the ten test wells ranged from 0.364 to 4.48 ug/L. In test well 4 (TW-4), the concentration measured was 37.1 ug/L. Figure 3 shows the January 2002 distribution of C-8 results in the production and test wells. Based on the elevated result at TW-4 compared to the surrounding wells, the Ohio Environmental Protection Agency (OEPA) requested that DuPont conduct a focused field investigation to delineate C-8 concentrations in soil and groundwater near TW-4.

In August 2002, DuPont conducted the field investigation at the Little Hocking Water Association well field. During this investigation, the following activities were performed:

- ☐ Advanced ten temporary soil borings
- ☐ Continuously monitored geologic information during the advancement of the ten temporary borings
- ☐ Sampled soil and groundwater and monitored groundwater parameters at various depths within the temporary borings

- ☐ Sampled groundwater in all production and test wells and recorded groundwater elevations
- ☐ Measured Ohio River stage

The C-8 Assessment of Toxicity Team (CATT), was assembled as required by the Consent Order to establish human health protective screening criteria for water (water C-8 SL) and for soil (soil C-8 SL). In August 2002, while the field investigation was being conducted at Little Hocking, the CATT issued its final report and established the water C-8 SL at 150 ug/L and the soil C-8 SL at 240 mg/kg (WVDEP, 2002).

Following the completion of the field activities at Little Hocking, groundwater samples were analyzed to measure C-8 concentrations. C-8 analytical results for groundwater were then compared to the CATT-established water C-8 SL. In August 2002, an analytical method for measuring C-8 in soils was still under development; therefore, soils sampled during the investigation were placed on-hold in a secure manner. The method development was completed in February 2003. C-8 analytical results for soils were finalized in March 2003. C-8 analytical results for soil were then compared to the CATT-established soil C-8 SL. The analytical results were then evaluated in conjunction with geologic data available from Little Hocking Water Association and with geological data obtained from the temporary borings. A site conceptual model was then developed.

This report documents the field investigation activities and the results of the investigation. In this report, the following sections are discussed:

- ☐ Environmental Setting (Section 2)
- ☐ Sampling Approach (Section 3)
- ☐ Groundwater Results (Section 4)
- ☐ Soil Sample Results (Section 5)
- ☐ The Little Hocking Site Conceptual Model (Section 6)
- ☐ Conclusions and Recommendations (Section 7)
- ☐ References (Section 8)

2.0 ENVIRONMENTAL SETTING

2.1 Geology

The Little Hocking well field is located in the Ohio River Valley and consists of Quaternary alluvial sediments that overlie the Permian-aged Dunkard Group. The two predominant facies of the Ohio River alluvium that have been identified in this area include coarse-grained Ohio River Alluvium (Pleistocene-aged glacial outwash deposits) and fine-grained Ohio River Alluvium [Holocene overbank deposits (Simard, 1989)]. The Pleistocene deposits consist primarily of coarse-grained sand and gravel while the Holocene deposits consist primarily of interbedded and laminated silt, clay and fine-grained sand. The Dunkard Group (bedrock) consists primarily of red and varicolored sandy shale; gray, green and brown sandstone; gray and light-gray siltstone; and minor beds of coal, claystone, black carbonaceous shale and limestone.

The facies of the Ohio River Alluvium formed in response to the glacial advances and retreats of the pre-, early- and late-Wisconsinan and were deposited as successive phases of aggradation and degradation of river valley alluvial materials. The coarse-grained Pleistocene alluvium was deposited as glacial outwash during the primary valley aggradation event following the glacial scouring of the valley into the bedrock floor. During the subsequent degradation and aggradation cycles of the Pleistocene, the glacial outwash sediments were partially removed, re-worked and then redeposited to a lower elevation than the previous cycle, thus forming a terrace. This process formed a series of Pleistocene-aged terrace surfaces within the Ohio River Valley. These surfaces were designated (youngest to oldest) as S4, S5, and S6 by Simard. With each subsequent degradation/aggradation cycle, additional fines were incorporated into the Pleistocene deposits due to continual influx of finer-grained fluvial sediments from tributaries of the Ohio River. As a result, the Pleistocene deposits become more highly re-worked and progressively finer-grained toward the center of the river valley, particularly in locations downstream of significant tributaries (Simard, 1989). The total thickness of Pleistocene sediments at Washington Bottom (located immediately south across the Ohio River from Little Hocking in West Virginia) ranges from about 80 feet beneath the highest Pleistocene terrace surfaces to about 15 feet beneath the current channel of the Ohio River.

The Pleistocene alluvial deposits are overlain by the finer-grained Holocene sediments. The silts, clays, and fine sands were deposited on the surface of the Pleistocene terraces as well as on a series of more recent floodplains, which formed in the center of the Ohio River Valley during the Holocene. The thickness of the Holocene sediments typically ranges from 5 to 15 feet over the Pleistocene terrace surfaces and 25 to 35 feet over the Holocene floodplains. Simard designated the Holocene floodplain surfaces as S1 through S3 and the modern floodplain of the Ohio River as S0. Figure 4, modified from Simard (1989), is a block diagram and idealized cross-section through the Ohio River valley depicting the complex set of Pleistocene terraces and Holocene floodplains which have formed in the valley.

A generalized north-south cross-section from the Little Hocking Water Association well field in Ohio, through the Ohio River and across the Washington Works facility, is presented in Figure 5. This cross-section shows the floodplain and terrace surfaces, the Holocene silt and clay overbank deposits overlying the Pleistocene sand and gravel outwash deposits and the re-worked Pleistocene alluvium in the center of the river valley. The alluvial terrace deposits are underlain by a flat, river-scoured bedrock surface of the Dunkard Group that rises steeply and forms the valley walls to the North of Little Hocking Water Association and to the south of the Washington Works facility (Figure 1).

2.2 Hydrogeology

Groundwater supplies in the region are obtained from the Dunkard Group bedrock and Ohio River alluvial terrace deposits. However, the saturated portion of the Ohio River alluvial terrace deposits comprise the principal regional aquifer used for water supply purposes. Production wells completed in this aquifer have been known to yield up to 500 gallons per minute (Schultz, 1984). Based on these high yields, numerous industrial and commercial water supply companies obtain water from the alluvial aquifer.

The Ohio River Alluvial Aquifer is the primary water-table aquifer in the area. This aquifer occurs at a depth of 15 to 30 feet below ground surface in the Little Hocking well field. The saturated zone is approximately 30 to 40 feet thick, extending approximately to the surface of the underlying Dunkard Group bedrock. Numerous pumping tests have been completed in the alluvial aquifer in the Washington Bottom area as part of water supply investigations. The hydraulic conductivity of the alluvial aquifer in the area typically ranges from 100 to 300 ft./d (Legggette, Brashears & Graham, Inc., 1986; Burgess & Niple Ltd., 1988). In contrast, the hydraulic conductivity of the underlying Dunkard Group bedrock aquifer is typically between 0.05 and 5 ft./d (Kozar and Mathes, 2001).

Natural recharge to the alluvial aquifer comes from various sources, including:

- ☐ Infiltration of precipitation falling directly on the alluvium
- ☐ Lateral movement of the river water through the alluvium
- ☐ Seepage from stream tributaries that discharge to the Ohio River
- ☐ Surface run-off from the outcrop areas of the Dunkard Group, which form steep slopes adjacent to the uppermost Pleistocene terrace.

3.0 SAMPLING APPROACH

In order to evaluate the elevated C-8 concentrations in TW-4, DuPont implemented a focused sampling approach that delineated horizontally and vertically the C-8 concentrations in groundwater near this test well. This sampling plan was developed with assistance from the OEPA and was submitted to and approved by the OEPA in early August 2002 (DuPont, 2002a). The locations of temporary borings advanced are shown in Figure 5. TW-4 was used as the center point, and six radial sampling segments were established north, northeast, southeast, south, west, and northwest. Along each segment, soil and groundwater or only groundwater were sampled from the temporary borings. Figure 5 shows the locations of the two borings where soil and groundwater were sampled and the locations of the eight borings where only groundwater was sampled. In two borings where soil and groundwater were sampled, sampling was planned at the following depths from ground surface.

- Soil
 - at the surface
 - at 5-foot intervals below ground surface to the top of the sand and gravel aquifer (approximately 30 feet below grade)
 - at 5-foot intervals from the top of the sand and gravel aquifer to the bottom of the aquifer (estimated at 50 to 55 feet below grade)
 - at the geologic interfaces
- Groundwater
 - at first encountered water (approximately 17 to 20 feet below grade)
 - at 5-foot intervals from first encountered groundwater to the bottom of the sand and gravel aquifer (estimated at 50 to 55 feet below grade).
 - at the geologic interfaces

At all other temporary boring locations, groundwater sampling was planned at two depths, at first encountered water (approximately 17 to 20 feet below grade) and at the bottom of the sand and gravel aquifer (estimated at 50 to 55 feet below grade).

In addition, DuPont scheduled the Consent Order-required 3Q02 PWS sampling event, which includes sampling the four production wells and TW-4 at Little Hocking, to coincide with the field investigation. The Little Hocking test wells, that are not required sampling points in the quarterly PWS sampling, were sampled as part of the field investigation, including TW-1 through TW-6 and TW-9 through TW-12 (Figure 2). Groundwater elevations were measured in the test and production wells prior to sampling the wells. Ohio River stage was also measured using the datum located on the Kraton Polymers property, located immediately east of the Little Hocking well field, with the assistance of a Senior Environmental Engineer from Kraton.

4.0 GROUNDWATER SAMPLE RESULTS

For groundwater sampled from production wells, test wells and the temporary borings, sampling was conducted as described in the Quality Assurance Project Plan (DuPont 2002b) and in the Sampling Investigation Plan for Little Hocking Water Association Well Field (DuPont, 2002a). Appendix A provides information on C-8 analytical reporting.

4.1 C-8 in Groundwater from Temporary Borings

Groundwater sampled at various depths from the ten temporary borings was analyzed for C-8. Table 1 presents the C-8 results for the groundwater samples. The first part of the sample name indicates the investigation and the sample type (WWO-G; Washington Works, Ohio, groundwater). The second part of the sample name indicates from which temporary boring the sample was collected (i.e. LHWAN1 is boring LHWAN-1; see Figure 6 for temporary boring locations). The third part of the sample name indicates the depth below ground surface from which the groundwater was sampled. Figure 7 shows the range in C-8 concentrations measured in each of the temporary borings.

In total, 18 samples (including one duplicate sample) were collected from the ten temporary borings (Table 1). Samples of first water encountered were collected from all ten borings. Samples from greater depths were collected from three borings. At the boring closest to TW-4, LHWASW-1, samples were collected every five feet from the first water encountered to the bottom of the sand and gravel aquifer. Note, not all planned sampling was completed. The field investigation proceeded slower than expected due to changing field conditions (stabilization of field parameters, particularly turbidity, took much longer than anticipated) and interruptions by the oversight consultant. As a consequence, not all groundwater and soils targeted in the work plan were sampled.

The C-8 concentrations measured in the groundwater sampled from temporary borings ranged from non-detectable (<0.01 ug/L; ND) to 78 ug/L and do not exceed the CATT-established human health protective water C-8 SL of 150 ug/L. In general, C-8 concentrations are higher at the first water encountered than at greater depths within the aquifer or at the bottom of the aquifer. The distribution of C-8 vertically and horizontally within the well field is discussed in detail in Section 6 which presents the site conceptual model for C-8 in soil and groundwater at Little Hocking.

4.2 C-8 in Groundwater from Production and Test Wells

Table 2 presents the PWS sampling C-8 results for the Little Hocking Water Association. The data for the well field investigation conducted in August 2002, including the data from the four production wells and all ten test wells are highlighted in blue. At the bottom of Table 2 are data from finished water and booster station sampling points. These are samples of the water that is being distributed to Little Hocking Water Association customers. Finished water was inadvertently not sampled during the well

field sampling. Table 2 also provides data from the 4Q02 and the 1Q03 PWS sampling events in which the four production wells, TW-4 and finished water were sampled. During the well sampling and PWS sampling, all of the C-8 concentrations measured in the production and test wells and in the finished water were well below the water C-8 SL of 150 ug/L that was established by the CATT (WVDEP, 2002).

Figure 7 shows the range of C-8 measured at each production and test well using all the data for each well summarized in Table 2. The highest concentration of C-8 measured in a production or test well, excluding TW-4, was 8.58 ug/L.

C-8 concentrations measured in TW-4, which was the focus of this investigation, have been variable. The C-8 concentration in this test well has ranged from 12.3 to 37.1 ug/L. These levels are higher than in any other test or production well in the Little Hocking well field. However, field and laboratory measurements and field observations, discussed below, suggest that the integrity of this test well is compromised.

Table 2 provides the pH data for the groundwater sampled collected from the production and test wells. The pH measured for all production and test wells, except for TW-4, has ranged from 6.72 to 7.94. However, the pH values measured in TW-4 are much higher, and have ranged from 9.22 to 12.61. High pH values are commonly associated with cement-bentonite grout (Colangelo et al. 1986).

Bentonite, which is commonly used as grouting material in well construction, is a clay mineral containing calcium, aluminum and iron. A comparison of groundwater analytical results between TW-4 and Well #2, one of the four production wells, also shows that TW-4 has approximately twice as much calcium and three times as much iron and aluminum than Well #2 (OEPA, 2002).

Field activities show that a three-inch pump that fits in the upper portion of the below-surface PVC pipe of TW-4, gets stuck in the PVC pipe at depth. The one and one half-inch pump, on the other hand, can be lowered to the bottom of the well. This observation indicates that the PVC pipe is not completely straight. A bent PVC pipe may indicate a problem with the joint between lengths of PVC pipe that could allow grout contamination into the well. Furthermore, particles of a crusty, white material, which may be grout, are frequently found on the pump when it is removed from the well. In addition, water from TW-4 also is frequently a milky to grayish color.

The consistently high pH values, water chemistry, and other field observations from this well likely indicate the integrity of the well is compromised, most likely by a failed grout seal or a failed well casing related to the bend in the PVC pipe. A failed grout seal or a failed well casing would allow shallow groundwater, which contains higher concentrations of C-8, to migrate into the deeper monitoring zone and would result in unusually high C-8 concentrations in the test well compared to C-8 concentrations measured in other production and test wells. Because of the compromised integrity of TW-4, it is likely that samples of groundwater from this well are not representative of typical conditions within the deeper portions of the sand and gravel aquifer.

The distribution of C-8 in the production and test wells in the Little Hocking well field is discussed in detail in Section 6, which presents the site conceptual model for C-8 in soil and groundwater in the Little Hocking Water Association well field.

4.3 Groundwater Elevations in Production and Test Wells and Ohio River Stage

Groundwater elevations were measured in all production and test wells sampled in the Little Hocking well field. In addition, the Ohio River stage was measured. Table 3 provides the surveyed measuring point elevations of the production and test wells, the depths to water measured and the calculated groundwater elevations. The Ohio River stage is also presented in this table.

Figure 8 presents the groundwater elevation contour map of the Little Hocking well field for August 21, 2002. The pumping of the production wells results in the development of a cone of depression surrounding the production wells with groundwater flowing towards the production wells from all directions. Because the four production wells are cycled on and off, the cone of depression shifts its position depending on which production wells that are pumping at the time. Groundwater elevations and flow directions within the Little Hocking well field aquifer are discussed in more detail in Section 6, which presents the site conceptual model for C-8 in soil and groundwater at the Little Hocking well field.

5.0 SOIL SAMPLE RESULTS

For soil sampled from the temporary borings, sampling was conducted as described in the Sampling Investigation Plan (DuPont, 2002b). In total, 22 soil samples, including one duplicate sample, were collected from two temporary borings, LHWASW-1 and LHWANW-1. Table 4 provides the sample names, sample dates, the C-8 concentration measured and comments. The sample nomenclature is similar to that employed for the groundwater samples. The first part of the sample name indicates the investigation and the sample type (WWO-S; Washington Works, Ohio, soil). The second part of the sample name indicates from which temporary boring the sample was collected (i.e. LHWASW1 is boring LHWASW-1). The third part of the sample name indicates the depth below ground surface where the sample was collected. The Comments column, on the far right, provides a brief description of the sample.

The C-8 concentrations measured from the two borings ranged from ND (<2 ug/kg) to 170 ug/kg in LHWASW-1 and from ND to 110 ug/kg in LHWANW-1 (Figure 9). In general, the concentrations of C-8 measured decreases with sampling depth in both of the temporary borings. The C-8 concentrations measured in soil from the temporary borings are significantly lower than the human health protective soil C-8 SL (240 mg/kg or 240,000 ug/kg) that was established by the CATT (WVDEP, 2002).

C-8 concentrations measured in soils from the Little Hocking well field are discussed in detail in Section 6, which presents the site conceptual model for C-8 in soil and groundwater at the Little Hocking Water Association well field.

6.0 SITE CONCEPTUAL MODEL

6.1 Geology

Using the geologic data available from the temporary borings and the production and test wells, three cross-sections (A-A', B-B', and C-C') were generated for the Little Hocking well field. Appendix B provides the geologic logs for the temporary borings. Geological logs for the production and test wells (made available to DuPont by the Little Hocking Water Association) are provided in Appendix C. The cross-section location map is provided in Figure 10. Cross-sections A-A' and B-B' generally run north to south and C-C' runs west to east. Cross-sections A-A', B-B', and C-C' are presented in Figures 11, 12, and 13, respectively. These cross-sections show that the stratigraphy of the Little Hocking well field is comprised of three lithological units (from ground surface downward):

- Holocene overbank deposits (approximately 25-40 feet of a low permeable silty clay or sandy clay or sand and clay)
- Pleistocene glacial outwash deposits (approximately 20-35 feet of sand and gravel which is the site aquifer)
- Dunkard Group bedrock (shale)

The composition of the Holocene overbank deposits is variable. In the western part of the well field, silty clay and clay are observed, while in the eastern portion sand and clay and/or sandy clay is found. The contact between the upper silty clay and the underlying sand and gravel is an erosional surface, characterized in some locations by channels cut into the sand and gravel (Figure 13). The composition of the sand and gravel unit is also variable, consisting of sand, sand and gravel, silty sand, and clayey sand. Where encountered in the temporary borings, the underlying bedrock is a micaceous, greenish gray siltstone. The logs for the production and temporary wells indicate that bedrock consists of red and blue shale, red clay and sandstone.

6.2 Hydrogeology

Cross-sections A-A', B-B' and C-C' also show the groundwater elevation for August 21, 2002 based on data measured at the production and test wells. At the time water levels were measured, Well #1, Well #2 and Well #3 were being pumped and Well #5 was not being used. The cone of depression around these three wells can be seen most obviously on cross-section C-C' (Figure 13), but can also be observed on B-B' (Figure 12). The groundwater contour map, which also shows the drawdown from the pumping wells, is provided in Figure 8. The hydraulic conductivity of the alluvial aquifer in the area typically ranges from 100 to 300 ft./day. Because of the high hydraulic conductivity, it is likely that the cone of depression shifts its position rapidly with the cycling on and off of the four production wells. Ohio River stage, 582.24 ft mean sea level, is higher than in

the test production and test wells. Therefore, water from the river flows into the site aquifer. Precipitation also is a minor recharge source for the Little Hocking well field.

6.3 C-8 Transport Mechanisms and Migration Pathways

Based on our current knowledge, the following paragraphs describe the transport mechanisms and migration pathways for C-8 from the Washington Works facility.

A groundwater model was developed for the Washington Works facility as part of the RFI report for Washington Works (DuPont, 1999). The Consent Order required refinement of the groundwater model for the facility to re-evaluate the extent of groundwater captured by the pumping wells at the site and to confirm that off-site migration of C-8 impacted groundwater is not occurring. To meet these requirements, refinement of the groundwater modeling work was completed with input, guidance, and critical review from the United States Geological Survey, the USACOE, the West Virginia Department of Health and Human Resources, and GIST members during the model development, calibration, and finalization process. The report of final findings for the revised groundwater model for the facility and the surrounding area was submitted to the GIST in January 2003 (DuPont, 2003). The revised groundwater model supports DuPont's previous conclusions that no off-site migration of groundwater is known to be occurring and that no potential groundwater migration pathway exists beneath the Ohio River to the Little Hocking well field.

However, DuPont had released, and continues to release, C-8 in air emissions from the Washington Works facility. C-8 is emitted to the atmosphere in two phases, a vapor phase, and a particulate phase. In May 2002, additional control equipment was installed at the facility to reduce C-8 emissions. There has been approximately a 65 percent decrease in total C-8 air emissions since the installation of this equipment compared to levels measured for 1999, when C-8 emission levels were at their highest. Continued reductions in C-8 emissions from the facility are anticipated during the next few years as abatement efficiency improvement projects are completed.

The Little Hocking well field is located directly north of the Washington Works facility across the Ohio River into Ohio. Wind direction data show that the Little Hocking well field is downwind of the facility and the predominant wind flow. Air emissions modeling by DuPont indicates that some C-8 in emissions from the Washington Works facility migrate over the Little Hocking well field.

Some C-8 in the vapor and particulate phases, emitted from the facility and transported by wind, is deposited on the surface soil at the Little Hocking well field. The concentrations of C-8 measured in surface soils (i.e. 0-1 foot depth) sampled during this investigation were 110 ug/kg and 170 ug/kg (Figure 11). C-8 is then leached by the precipitation from surface soils to surface-water bodies and/or infiltration into surface soils.

Dissolved C-8 continues migrating downward in the unsaturated zone with the infiltrating precipitation. The C-8 concentration in the soils below the surface, in the unsaturated zone, ranged from 3.4 to 13 ug/kg, almost an order of magnitude lower than the concentrations of C-8 measured at the surface (see LHWAN-1 and LHWASW-1 in

Figure 11). The low permeability of the upper silty clay likely slows the rate of downward migration of precipitation. In addition, the rate and direction of migration of precipitation likely changes with the different lithologies encountered in the Holocene overbank deposits. For example, precipitation might migrate slowly downward through the silty clay and then migrate laterally in a sand lens at a much faster rate. Soil-type differences may also be responsible for the highly variable C-8 concentrations measured within the groundwater in silty clay unit (compare LHWAS-1 with C-8 concentration of nondetectable to LHWAS-2 having C-8 at 78 ug/L). In addition, the rate of precipitation and the level of the water table likely have some control over the rate of migration of dissolved C-8. However, because C-8 is highly soluble (Fluoropolymers Manufacturers Group, 2001), it does not tend to precipitate or sorb to particles in the soil but it remains in solution and migrates with groundwater.

The concentrations of C-8 in groundwater at the top of the water table are higher than the concentration of C-8 just below at the lithologic contact between the silty clay and the sand and gravel (Figure 11). These data indicate that the overall the concentration of C-8 decreases with depth in the water table within the silty clay. Alternatively, these data also may reflect the increased permeability in the sand and gravel compared to the silty clay.

The C-8 concentration measured in a single boring at various depths show that the concentration of C-8 in groundwater and soil decreases with depth within the aquifer (Figure 11) as the dissolved C-8 migrates within the sand and gravel aquifer. However, the C-8 concentration at the base of the sand and gravel aquifer (i.e. position of the well screens) is somewhat variable and does not seem to show a trend with groundwater flow direction towards the pumping wells. Table 2 shows that C-8 concentrations are consistent within a single production well but that the concentrations are different between the production wells. Well #3 consistently has the lowest C-8 concentration (less than 1 ug/L) whereas Well #5 consistently has the highest C-8 concentration (ranging from 5.69 to 8.59 ug/L). Because the four production wells are cycled on and off and the C-8 concentrations measured in the wells are not the same, the C-8 concentration in the finished water is variable. Table 2 shows the concentration of C-8 in finished water has ranged from 1.69 to 4.29 ug/L.

Briefly summarized, DuPont currently believes that C-8 from the DuPont facility is transported via air emissions by wind and is deposited on the Little Hocking well field surface soils. Precipitation leaches the C-8 downward through the unsaturated zone to the aquifer. Dissolved C-8 then migrates with groundwater within the aquifer. Groundwater containing low levels of C-8 is then pumped from the aquifer through the production wells. Water from the four production wells is mixed and water containing even lower levels of C-8 (the finished water) then enters the Little Hocking Water Association distribution system. C-8 concentrations in finished water from Little Hocking are significantly below the human health protective water C-8 SL of 150 ug/L (WVDEP 2002).

7.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the investigation at the Little Hocking Water Association well field and other data available, the following conclusions can be made:

- ❑ All groundwater results are below the C-8 Assessment of Toxicity Team (CATT) established human health protective screening criteria for water (water C-8 SL; WVDEP 2002) of 150 ug/L.
- ❑ The C-8 concentrations in groundwater decreased with depth within the aquifer. The C-8 concentrations in groundwater at the top of the aquifer, within the silty clay, ranged from ND (<0.01 ug/L) to 78 ug/L, while C-8 concentrations at the bottom of the aquifer, within the sand and gravel, ranged from ND (<0.01 ug/L) to 8.58 ug/L (excluding results for TW-4).
- ❑ Consistently high pH values measured in TW-4 and other field observations indicate that this test well's construction is likely compromised, possibly due to a failed grout seal or to a failed well casing. Higher concentrations of C-8 measured in this well (ranging from 12.3 to 37.1 ug/L) are likely attributed to shallow groundwater that contains higher C-8 concentrations migrating downward into the deeper monitoring zone or into the well itself, which could happen if the grout seal or the well casing were to have failed. C-8 concentrations measured in this well are not likely to be truly representative of the deep aquifer.
- ❑ Drinking water is pumped from the bottom of the sand and gravel aquifer through the four production wells. The highest C-8 concentration measured in the four production wells was 8.58 ug/L, significantly lower than the human health protective water C-8 SL. The C-8 results for finished water, a combination of waters from the production wells that is distributed to Little Hocking customers, ranged from 1.69 to 4.29 ug/L, also significantly lower than the water C-8 SL.
- ❑ All soil results are below the CATT-established human health protective screening criteria for soil (soil C-8 SL) of 240 mg/kg (WVDEP 2002). The highest soil C-8 concentration measured is 170 ug/kg (0.170 mg/kg). Most results for soil sampled below the water table are nondetectable.
- ❑ Overall, the very low concentrations of C-8 measured in the soils indicate that C-8 does not readily adsorb to soil, especially soils below the water table.
- ❑ C-8 results for soil and groundwater sampled immediately adjacent to TW-4 do not distinguish this test well as a source for higher C-8 concentrations in soil and groundwater.
- ❑ Overall, this investigation as completed, combined with the air emission modeling and groundwater modeling results and the available physiochemical data for C-8, are sufficient to understand the migration pathways of C-8 from the Washington Works facility and within the Little Hocking Water Association well field.

- Revised groundwater modeling by DuPont supports the previous conclusion that no potential groundwater migration pathway exists beneath the Ohio River to the Little Hocking Well field.
- Based on the current data available, DuPont believes the following pathway does exist. C-8 from the DuPont facility is transported via air emissions by wind and is deposited on the Little Hocking well field surface soils. Precipitation then leaches the C-8 downward through the unsaturated zone to the aquifer. Dissolved C-8 then migrates with groundwater within the aquifer. Groundwater containing low levels of C-8 is then pumped from the aquifer through the four production wells. Water from the production wells is mixed and the finished water, containing even lower levels of C-8, then enters the Little Hocking Water Association distribution system.
- This investigation as completed, combined with the overall understanding of C-8 migration pathways within the Little Hocking well field, is also sufficient to understand the distribution of C-8 in the test wells, including TW-4, in the production wells and in the finished water that enters the Little Hocking distribution system.
- In order to assess the impact of recent C-8 air emission reductions at the Washington Works facility, DuPont recommends continuing quarterly monitoring of C-8 in the four Little Hocking Water Association production wells and finished water for a period of two years.

8.0 REFERENCES

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TABLES

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Table 1
C-8 in Groundwater from Temporary Borings
Little Hocking Water Association
Washington County, Ohio

Sample Name	Sample Date	Depth (ft)	Description
WWO-G-LHWAN1 (17-22)	8/29/02	50.8	first water encountered
WWO-G-LHWAN1 (21-27)*	8/20/02	5.58	first water encountered
WWO-G-LHWAN1 (56-58)	8/22/02	0.662	bottom of sand and gravel
WWO-G-LHWAN2 (20.7-25.7)	8/30/02	1.28	first water encountered
WWO-G-LHWAE1 (21-26)	8/30/02	0.416	first water encountered
WWO-G-LHWAS1 (25-30)	8/28/02	ND (<0.01)	first water encountered
WWO-G-LHWAS2 (25-30)	8/27/02	78	first water encountered
WWO-G-LHWASW1 (28.5-33)	8/23/02	0.0912	first water encountered
WWO-G-LHWASW1 (35-40)*	8/26/02	1.32	every 5 ft groundwater sample
WWO-G-LHWASW1 (40-45)	8/26/02	1.02	every 5 ft groundwater sample
WWO-G-LHWASW1 (45-50)	8/28/02	0.376	every 5 ft groundwater sample
WWO-G-LHWASW1 (50-55)	8/28/02	0.166	every 5 ft groundwater sample
WWO-G-LHWASW1 (55-56)*	8/28/02	0.254	bottom of sand and gravel
WWO-G-LHWAW1 (29-34)	8/29/02	ND (<0.01)	first water encountered
WWO-G-LHWAW2 (33-38)	8/29/02	3.35	first water encountered
WWO-G-LHWANW1 (19-25)	8/29/02	34.6	first water encountered
WWO-G-LHWANW1 (24-29)	8/29/02	5.9	top of sand and gravel
WWO-G-LHWANW1 (24-29)-2(DUP)	8/29/02	6.22	top of sand and gravel

* Sample split with the Ohio EPA.

4/17/03

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LH samples

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Table 2
C-8 in Production and Test Wells
Little Hocking Water Association
Washington County, Ohio

Well	Sample Name	Sample Date	C-8 ug/l	Comments	pH
Well #1	LHPSD1	12/20/01	1.82	Production Well	7.19
	LHPSD1	1/21/02	1.72	Production Well	7.68
	LHPSD1	2/22/02	2.37	Production Well	6.97
	LHPSD1	3/26/02	2.99	Production Well	7.30
	LHPSD1	4/23/02	2.02	Production Well	8.03
	LHPSD1	8/21/02	3.65	Production Well	6.79
	LHPSD1	10/16/02	3.41	Production Well	6.97
	LHPSD1	2/26/03	3.38	Production Well	6.72
Well #2	LHPSD2	12/20/01	3.72	Production Well	7.08
	LHPSD2	12/20/01	3.52	duplicate	---
	LHPSD2	1/21/02	2.97	Production Well	7.74
	LHPSD2	2/22/02	2.03	Production Well	7.61
	LHPSD2	2/22/02	2.07	duplicate	---
	LHPSD2	3/26/02	3.31	Production Well	7.56
	LHPSD2	4/23/02	3.4	Production Well	7.76
	LHPSD2	8/21/02	4.26	Production Well	7.39
	LHPSD2	10/16/02	3.98	Production Well	7.5
Well #3	LHPSD3	12/20/01	0.844	Production Well	7.25
	LHPSD3	1/21/02	0.744	Production Well	7.83
	LHPSD3	2/22/02	0.42	Production Well	7.65
	LHPSD3	3/26/02	0.827	Production Well	7.73
	LHPSD3	4/23/02	0.783	Production Well	7.94
	LHPSD3	8/21/02	0.952	Production Well	7.68
	LHPSD3	10/16/02	0.495	Production Well	7.77
	LHPSD3	10/16/02	0.434	duplicate	---
	LHPSD3	2/26/03	0.733	Production Well	7.44
Well #5	LHPSD5	12/20/01	7.66	Production Well	7.04
	LHPSD5	1/21/02	6.22	Production Well	7.4
	LHPSD5	1/21/02	6.14	duplicate	7.39
	LHPSD5	2/22/02	5.69	Production Well	7.26
	LHPSD5	3/26/02	6.57	Production Well	7.40
	LHPSD5	4/23/02	6.11	Production Well	7.52
	LHPSD5	8/21/02	8.09	Production Well	7.2
	LHPSD5	10/16/02	8.58	Production Well	7.41
	LHPSD5	2/26/03	6.93	Production Well	7.16
TW-1	LHPSDTW1	1/22/02	2.16	Test well	7.87
	LHPSDTW1	8/21/02	0.81	Test well	7.41
TW-2	LHPSDTW2	1/22/02	0.103	Test well	7.62
	LHPSDTW2	8/21/02	0.081	Test well	7.03
TW-3	LHPSDTW3	1/22/02	4.48	Test well	7.42
	LHPSDTW3	8/21/02	4.17	Test well	7.13

4/17/03

Page 1 of 2

LH samples

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Table 2
C-8 in Production and Test Wells
Little Hocking Water Association
Washington County, Ohio

Sample Name	Sample Name	Sample Date	C-8 ug/l	Comments	pH
TW-4	LHPSDTW4	1/22/02	37.1	Test well	12.61
	LHPSDTW4	3/26/02	33.3	Test well	12.26
	LHPSDTW4	4/23/02	28.7	Test well	12.35
	LHPSDTW4	8/21/02	12.3	Test well	11.32
	LHPSDTW4	10/18/02	14.5	Test well	9.22
	LHPSDTW4	2/26/03	22.5	Test well	10.54
TW-5	LHPSDTW5	8/21/02	6.26	Test well	6.7
TW-6	LHPSDTW6	1/22/02	1.79	Test well	7.03
	LHPSDTW6	8/21/02	1.15	Test well	6.81
	LHPSDTW6	8/21/02	1.23	duplicate	6.81
TW-9	LHPSDTW9	1/22/02	0.364	Test well	7.33
	LHPSDTW9	8/21/02	0.812	Test well	7.09
TW-10	LHPSDTW10	1/21/02	1.9	Test well	7.43
	LHPSDTW10	8/21/02	1.1	Test well	6.85
TW-11	LHPSDTW11	1/21/02	1.41	Test well	7.38
	LHPSDTW11	8/21/02	1.73	Test well	7.07
TW-12	LHPSDTW12	1/21/02	0.758	Test well	7.39
	LHPSDTW12	8/21/02	0.824	Test well	6.9
LHPSDEP001	LHPSDEP001	1/22/02	1.69	Finished Water	
LHPSDEP001	LHPSDEP001	3/26/02	2.62	Finished Water	
LHPSDEP001	LHPSDEP001	4/23/02	1.93	Finished Water	
LHPSDEP001	LHPSDEP001	10/18/02	4.29	Finished Water	
LHPSDEP001	LHPSDEP001	2/26/03	2.33	Finished Water	
LHTORCHBS	LHTORCHBS	1/22/02	1.85	Booster Station Sample	
BARTLETTCC	BARTLETTCC	1/22/02	1.94	Booster Station Sample	
339B STA	339B STA	1/22/02	1.81	Booster Station Sample	

Shaded cells indicate groundwater sampled for the Little Hocking Sampling Investigation in August 2002.

Table 3
Groundwater Elevation Data for Production and Test Wells August 2002
Little Hocking Water Association
Washington County, Ohio

Well ID	Surveyed Elevation	Depth to Water (8/21/02)	Groundwater Elevation (feet MSL)
Well #1	613.47	56.88	556.59
Well #2	613.71	42.88	570.83
Well #3	613.54	39.88	573.66
Well #5	613.18	35.62	577.56
TW-1	598.13	17.38	580.75
TW-2	599.92	18.63	581.29
TW-3	599.75	22.78	576.97
TW-4	598.52	18.16	580.36
TW-5	608.28	30.63	577.65
TW-6	598.7	19.03	579.67
TW-9	598.53	21.44	577.09
TW-10	595.83	17.77	578.06
TW-11	603.79	26.57	577.22
TW-12	602.22	23.95	578.27
Ohio River	584.7	2.46	582.24

*Elevations were surveyed by Bob Griffin of LHWA on 8/23/02 using 610.0 as reference assumption for PW-1 well house top of floor slab.

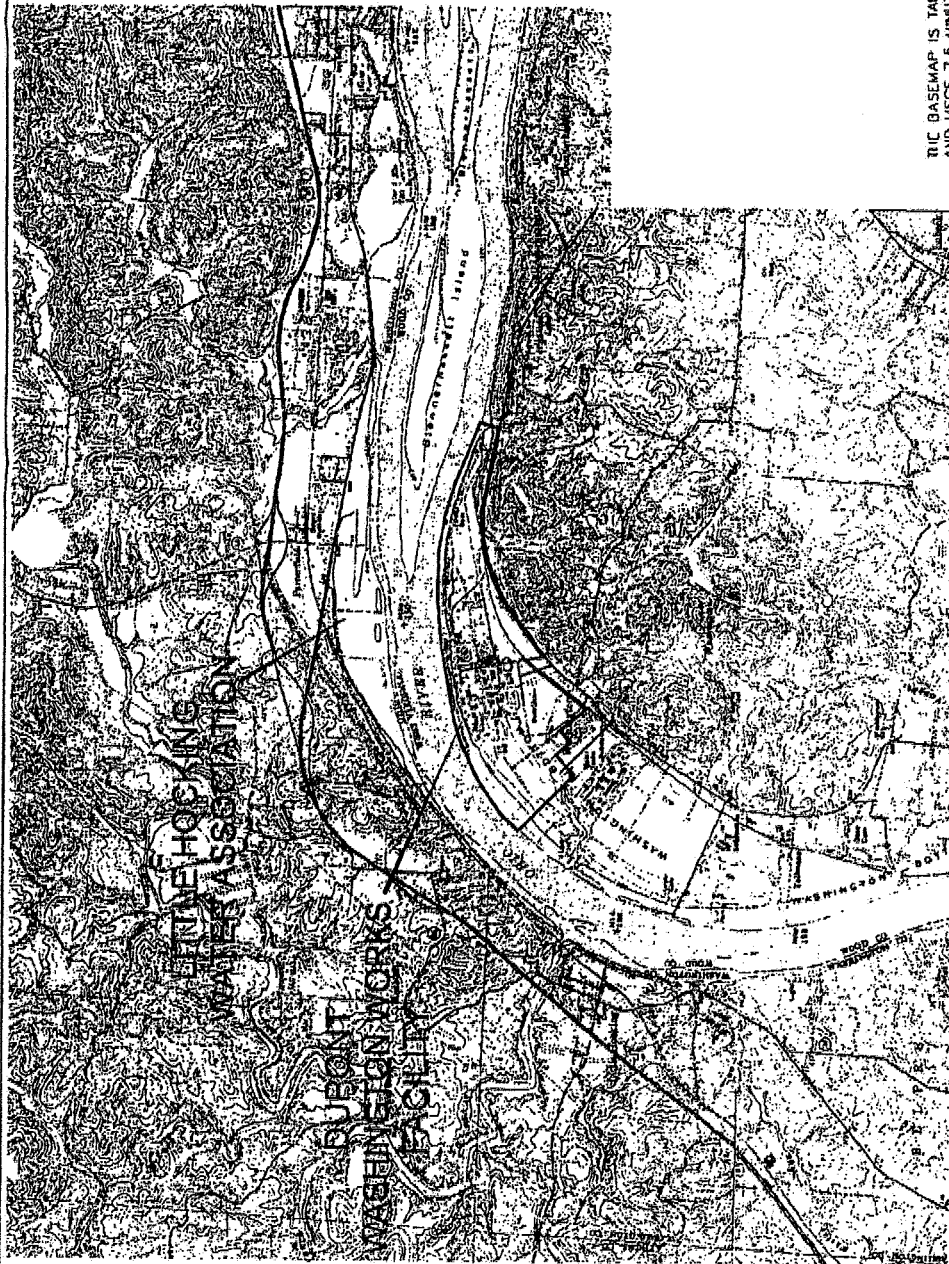
Table 4
C-8 in Soil from Temporary Borings
Little Hocking Water Association
Washington County, Ohio

Sample Name	Sample Date	C-8 (ug/kg)	Comments
WWO-S- LHWASW1 (3-9)	8/23/02	170	surface soil
WWO-S- LHWASW1 (5.0-5.6)	8/23/02	13	every 5 ft soil sample
WWO-S- LHWASW1 (11.2-11.7)	8/23/02	3.4	every 5 ft soil sample
WWO-S- LHWASW1 (15.5-16.0)	8/23/02	3.3	every 5 ft soil sample
WWO-S- LHWASW1 (22.1-22.6)	8/23/02	NQ	every 5 ft soil sample
WWO-S- LHWASW1 (28.5-27.0)	8/23/02	ND(0.18)	every 5 ft soil sample
WWO-S- LHWASW1 (30.0-30.5)	8/23/02	ND(0.18)	geologic interface
WWO-S- LHWASW1 (30.5-31.0)	8/23/02	ND(0.19)	geologic interface
WWO-S- LHWASW1 (37.0-37.5)	8/26/02	NQ	lithology change
WWO-S- LHWASW1 (37.5-38.0)	8/26/02	ND(0.19)	every 5 ft soil sample, charcoal layer
WWO-S- LHWASW1 (44.3-44.5)	8/26/02	NQ	every 5 ft soil sample
WWO-S- LHWASW1 (47.5-48.0)	8/26/02	ND(0.18)	every 5 ft soil sample
WWO-S- LHWASW1 (53.5-54.0)	8/28/02	ND(0.18)	every 5 ft soil sample, duplicate
WWO-S- LHWASW1 (53.5-54.0)-2	8/28/02	ND(0.17)	every 5 ft soil sample
WWO-S- LHWASW1 (55.5-56.0)	8/28/02	ND(0.17)	every 5 ft soil sample
WWO-S- LHWANW1 (0.1-0.5)	8/29/02	110	surface soil
WWO-S- LHWANW1 (5.0-5.5)	8/29/02	6.1	every 5 ft soil sample
WWO-S- LHWANW1 (10.0-10.5)	8/29/02	7.5	every 5 ft soil sample
WWO-S- LHWANW1 (15.0-15.5)	8/29/02	6.9	every 5 ft soil sample
WWO-S- LHWANW1 (20.0-20.5)	8/29/02	17	geologic interface
WWO-S- LHWANW1 (21.0-21.5)	8/29/02	18	geologic interface
WWO-S- LHWANW1 (25.0-25.5)	8/29/02	8.4	every 5 ft soil sample

ND = not detected at the listed method detection limit (MDL).
 NQ = detected at a level between the MDL and the reporting limit (RL); result is not quantifiable.
 ND < MDL < NQ < RL
 RL = limit of quantitation (LOQ) adjusted for actual sample weight and % moisture.
 nominal LOQ = 2 ug/kg.

FIGURES

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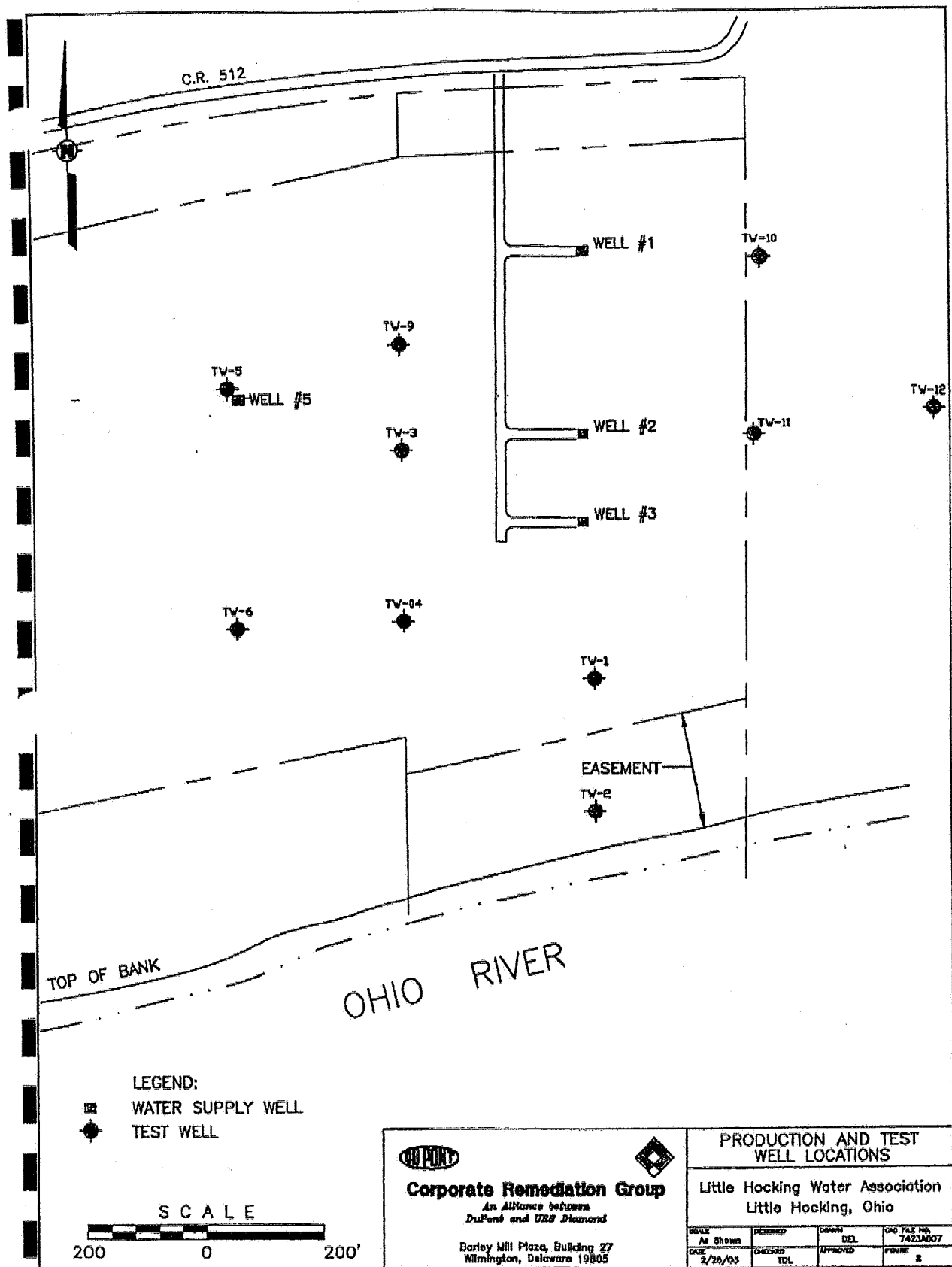


RIC BASEMAP IS TAKEN FROM THE BELPRE, OH, LUBCK, WV
AND USGS 7.5 MINUTE QUADRANGLE MAPS.

Corporate Remediation Group In various locations DuPont and E&S Chemical Bailey Mill Plant, Building 27 Washington, Delaware 19385		SITE LOCATION MAP DuPont Washington Works Washington, West Virginia	
DATE	BY	SCALE	REVISION

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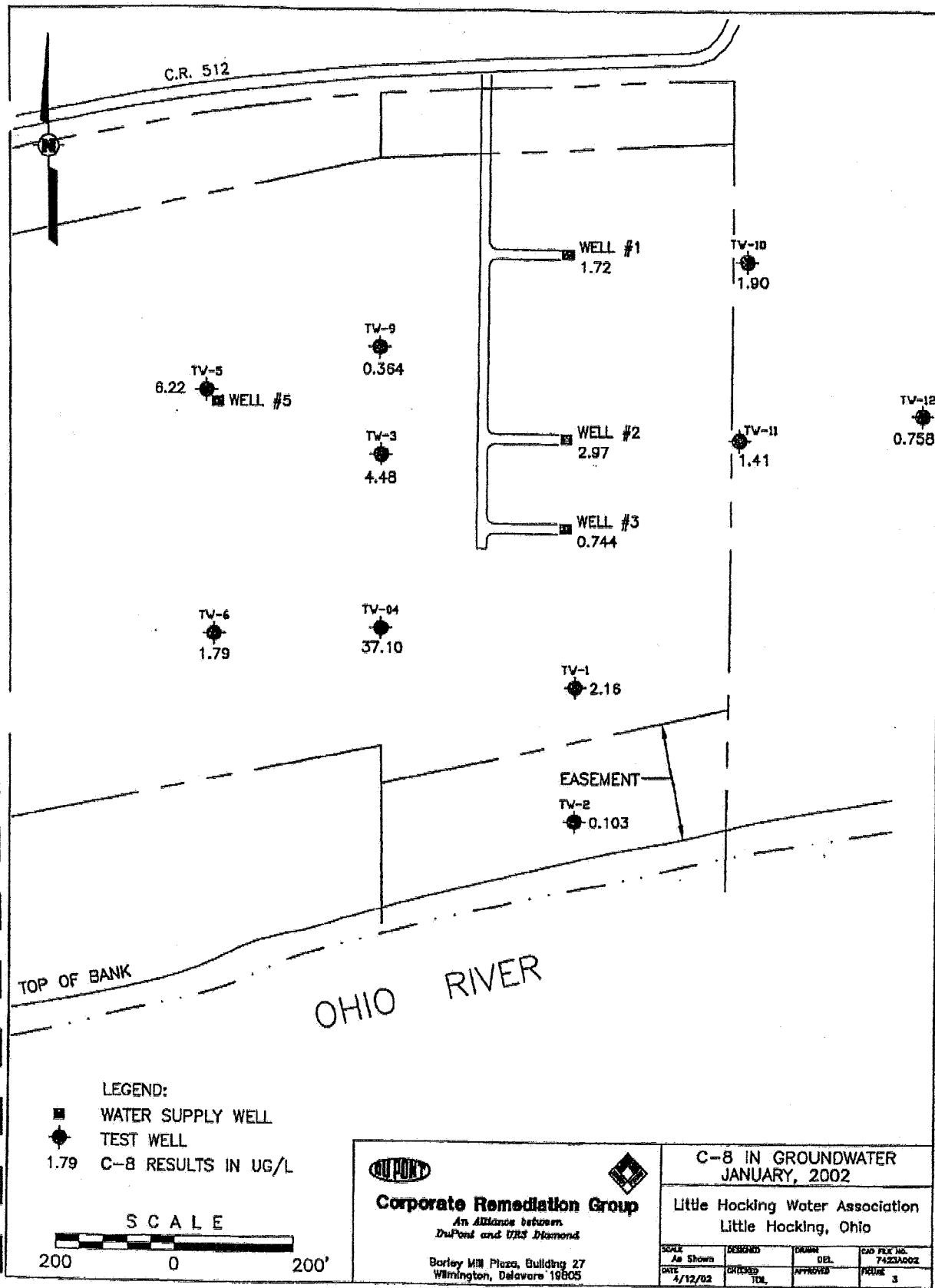
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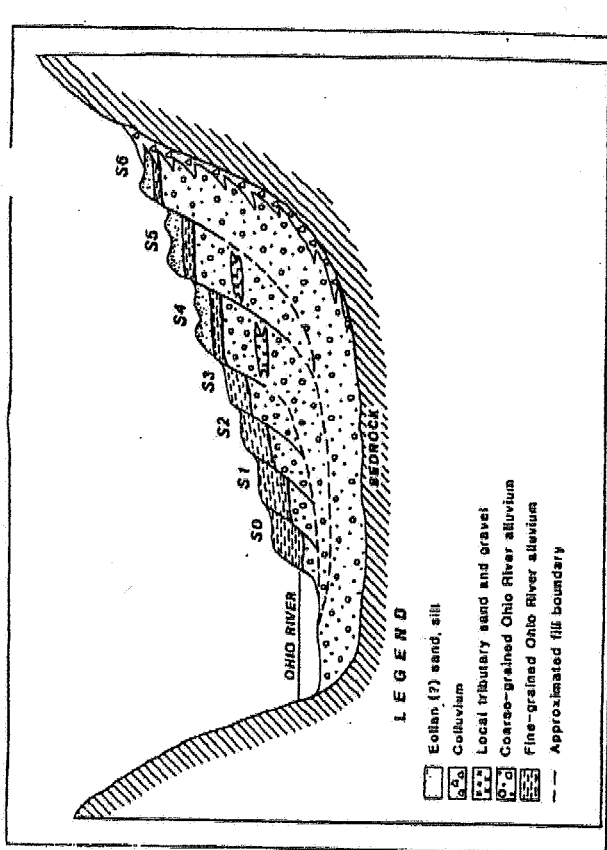
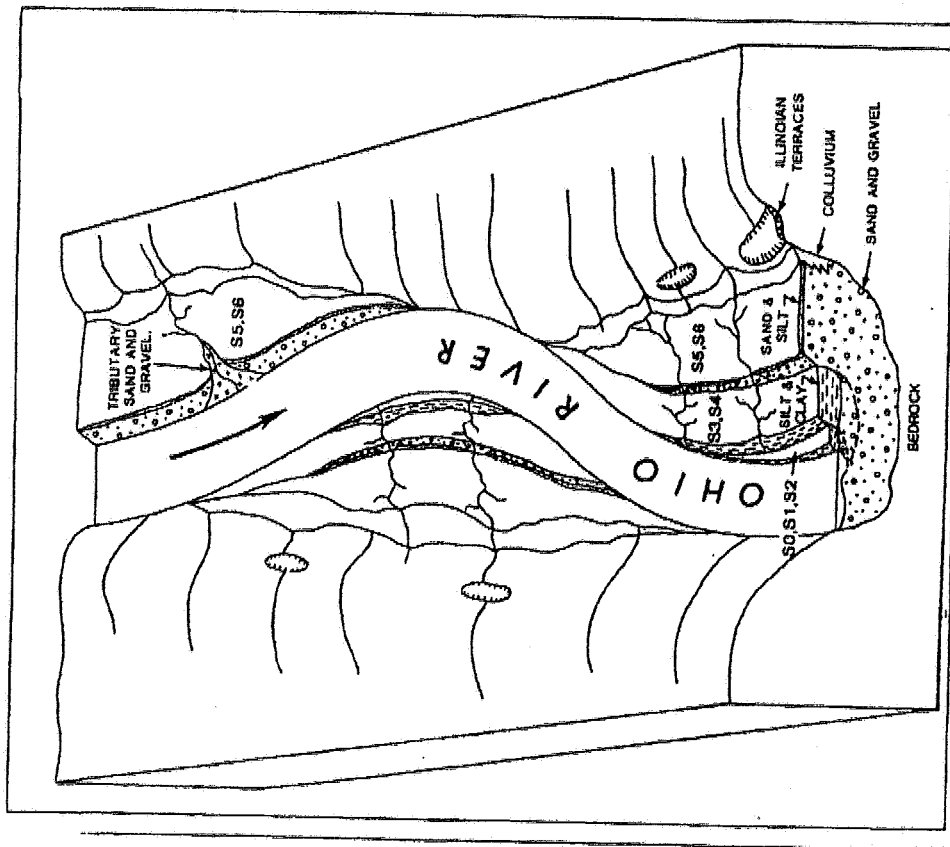
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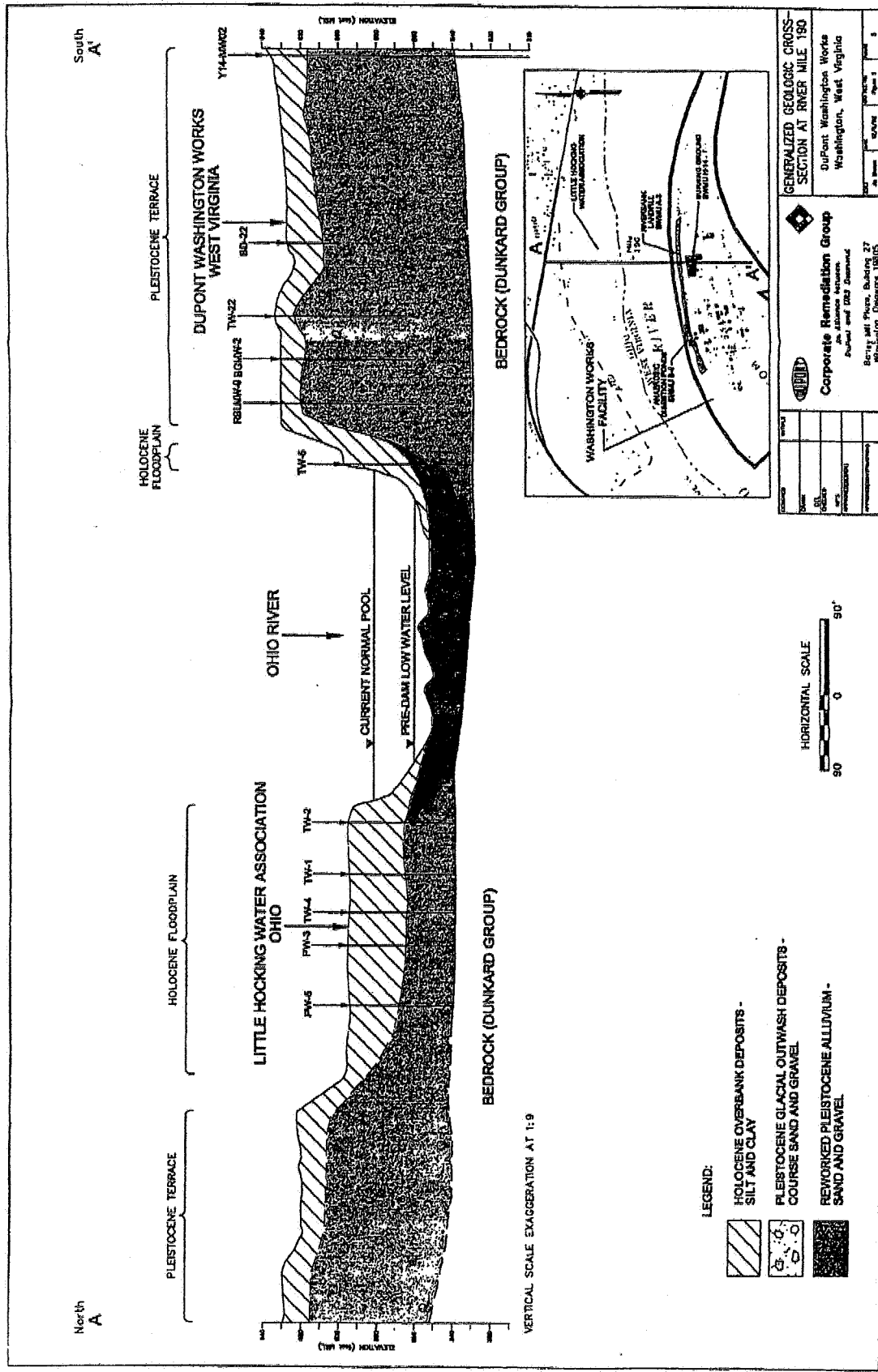
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ILLUSTRATIONS TAKEN FROM SIMARD, 1989.

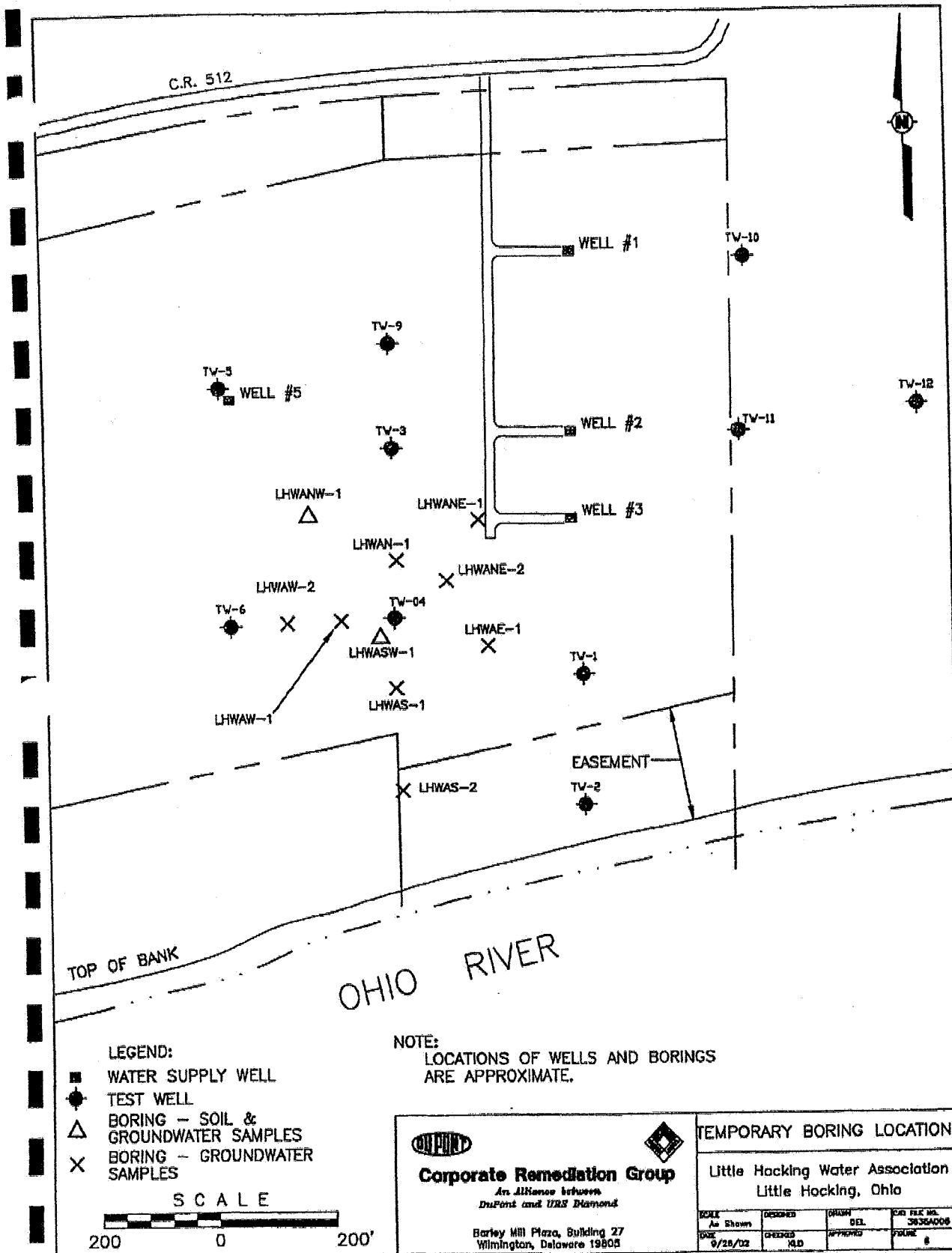
IDEALIZED OHIO RIVER VALLEY CROSS-SECTION AND BLOCK DIAGRAM	
DuPont Washington Works Washington, West Virginia	
Corporate Remediation Group An Atlantic Richfield DuPont and OGC Asset	
Barley Hill Plaza, Building 27 Washington, Delaware 19380	
Scale	1:10,000
Sheet	1 of 1



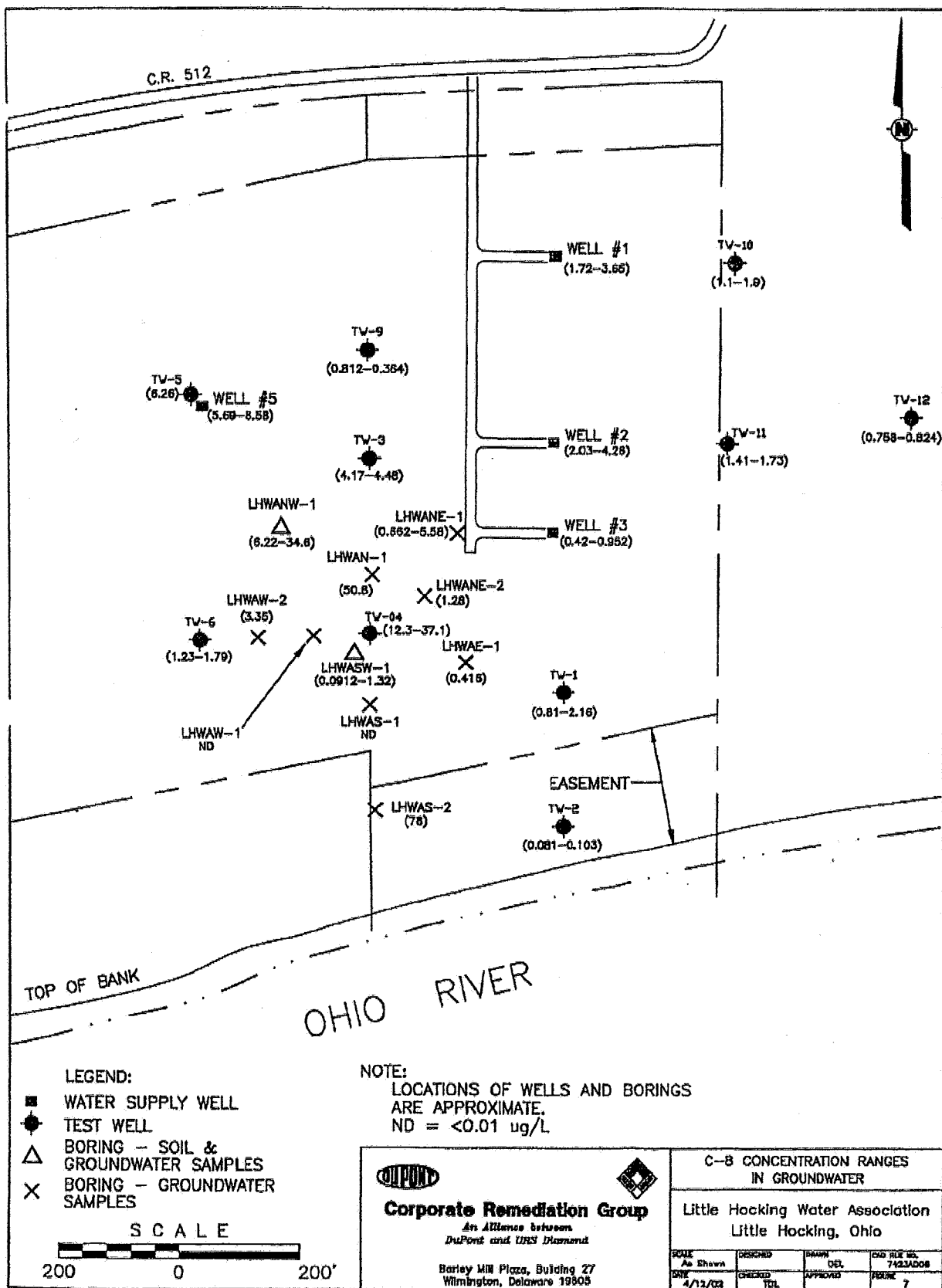
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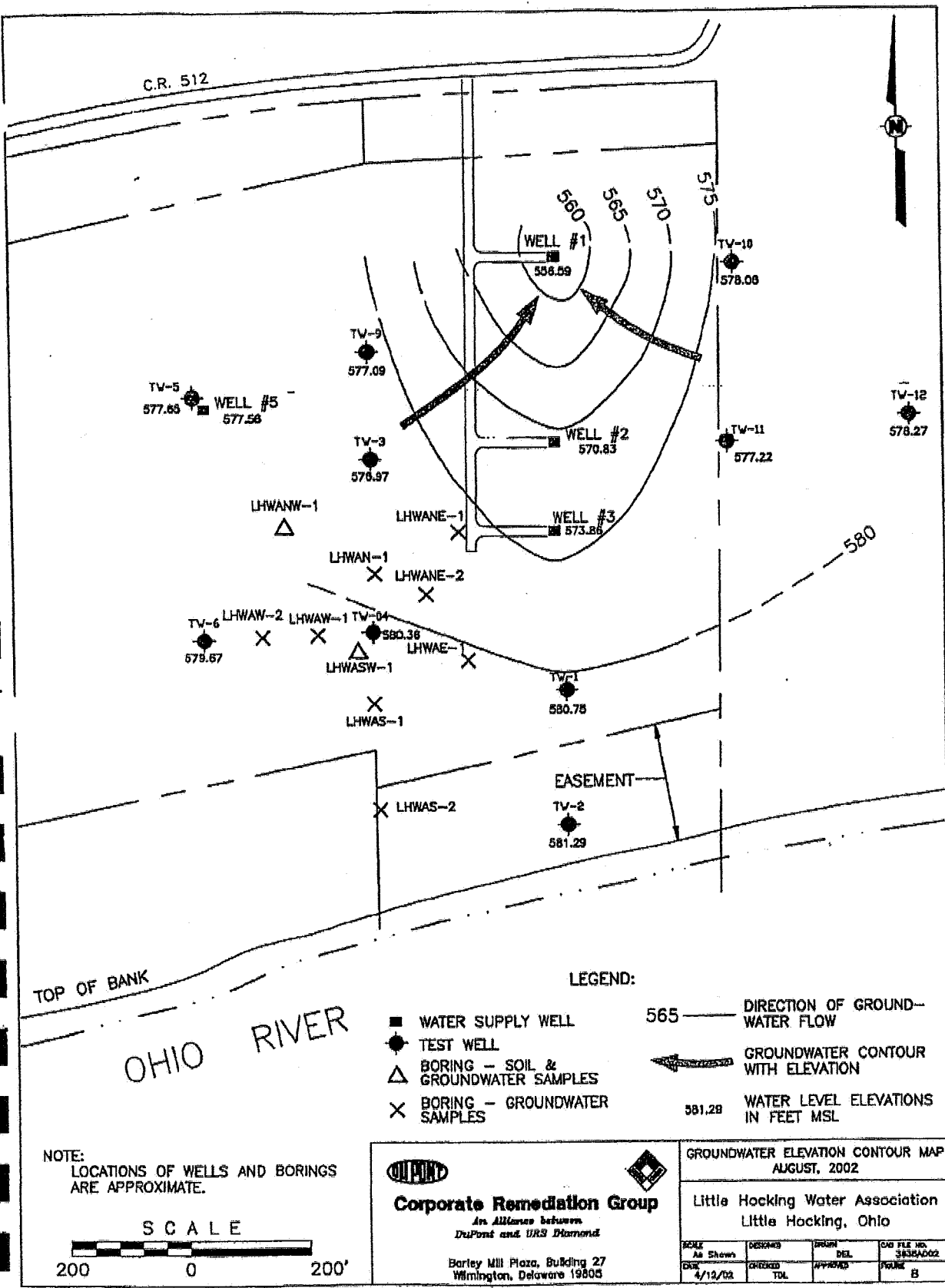
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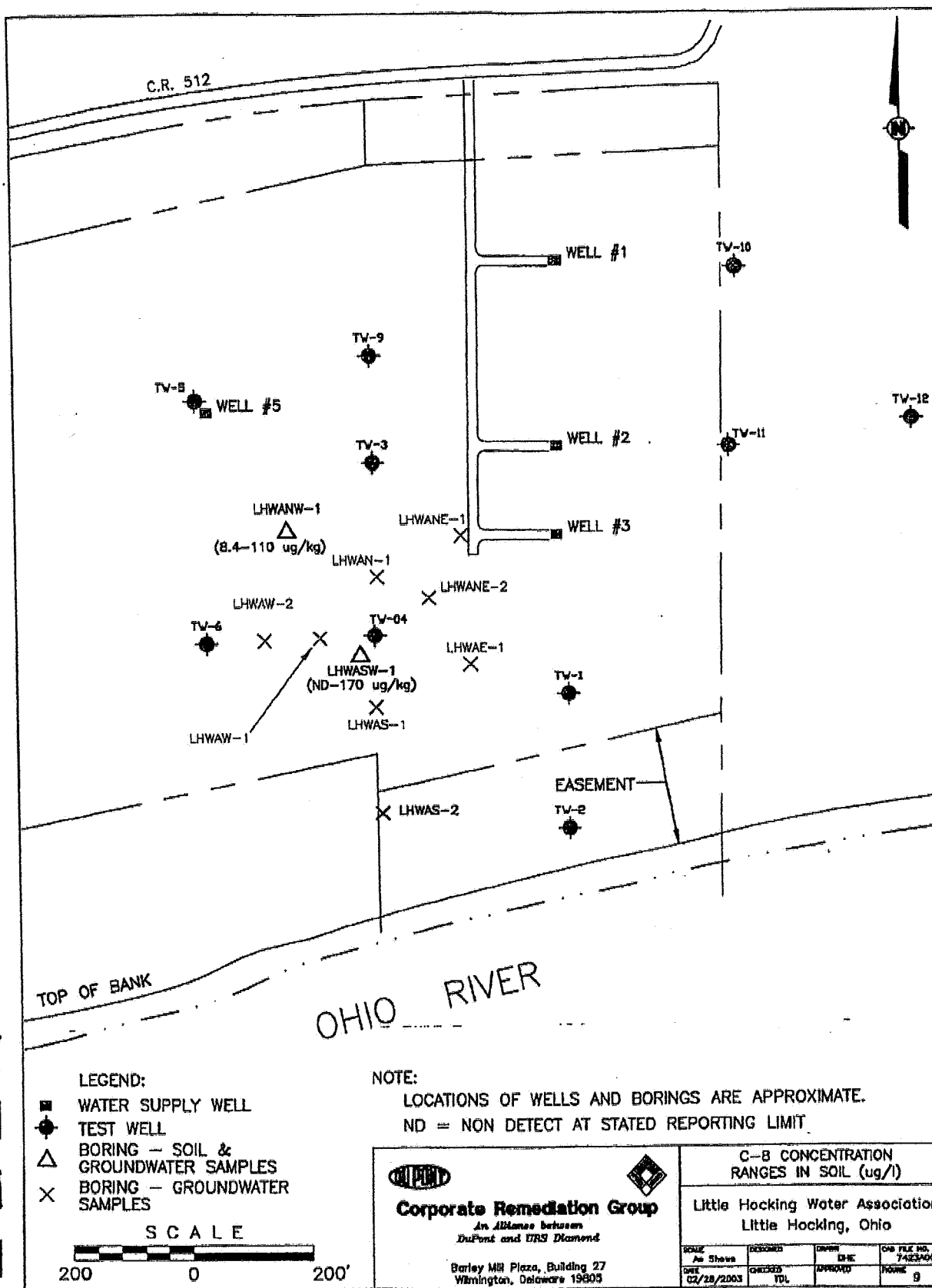
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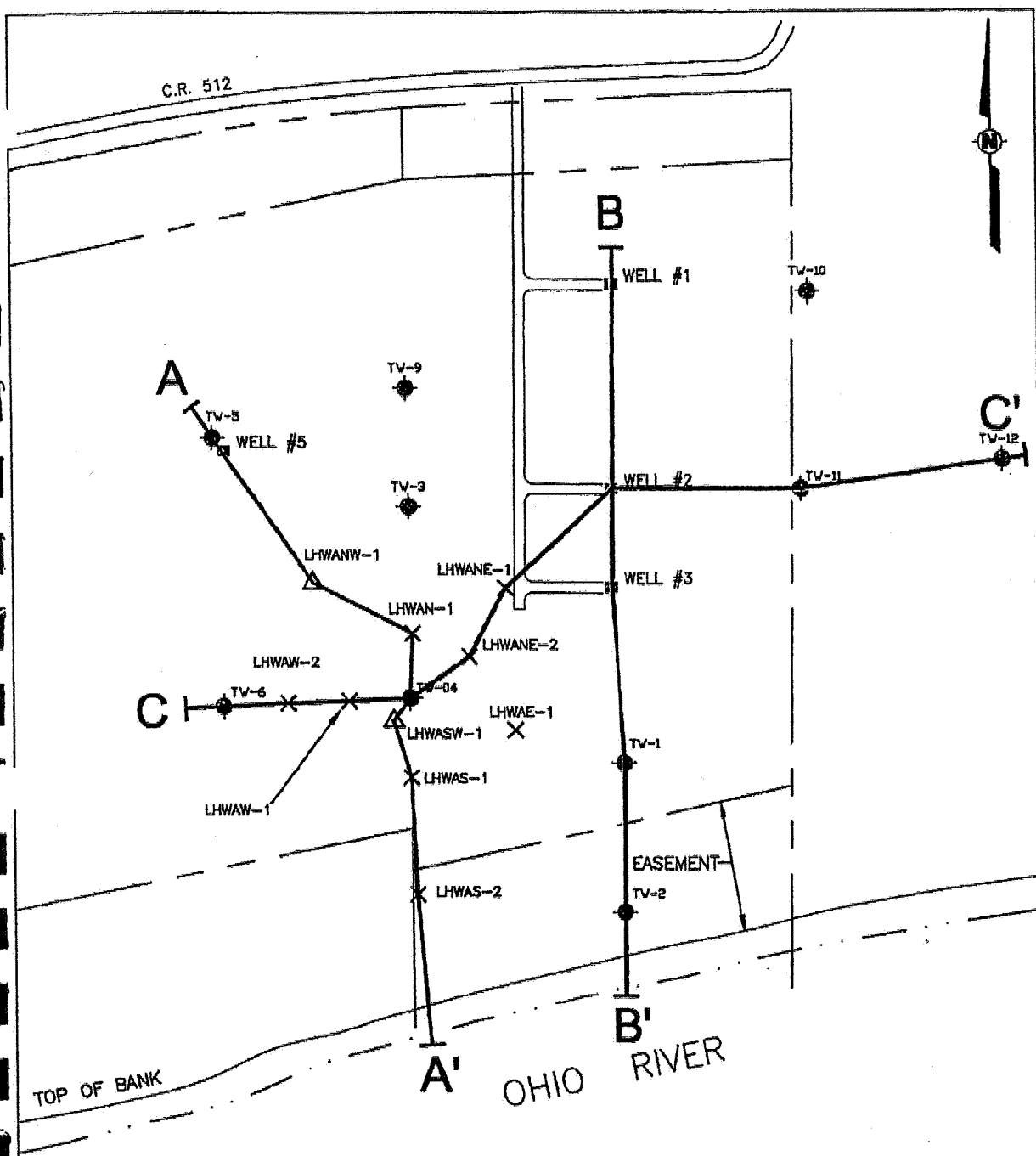
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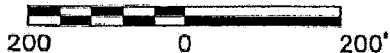
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LEGEND:

- WATER SUPPLY WELL
- TEST WELL
- △ BORING - SOIL & GROUNDWATER SAMPLES
- × BORING - GROUNDWATER SAMPLES

SCALE



NOTE:

LOCATIONS OF WELLS AND BORINGS ARE APPROXIMATE.



Corporate Remediation Group

An Alliance between
DuPont and UNIS Diamond

Barley Mill Plaza, Building 27
Wilmington, Delaware 19806



CROSS-SECTION LOCATION MAP

Little Hocking Water Association
Little Hocking, Ohio

DATE	DESIGNED	DRAWN	CHECKED	DATE	FILE NO.
As Shown		DHE			3636A008
03/20/02	CHD	APPROVED			FIGURE 10

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**SOUTH
A'**

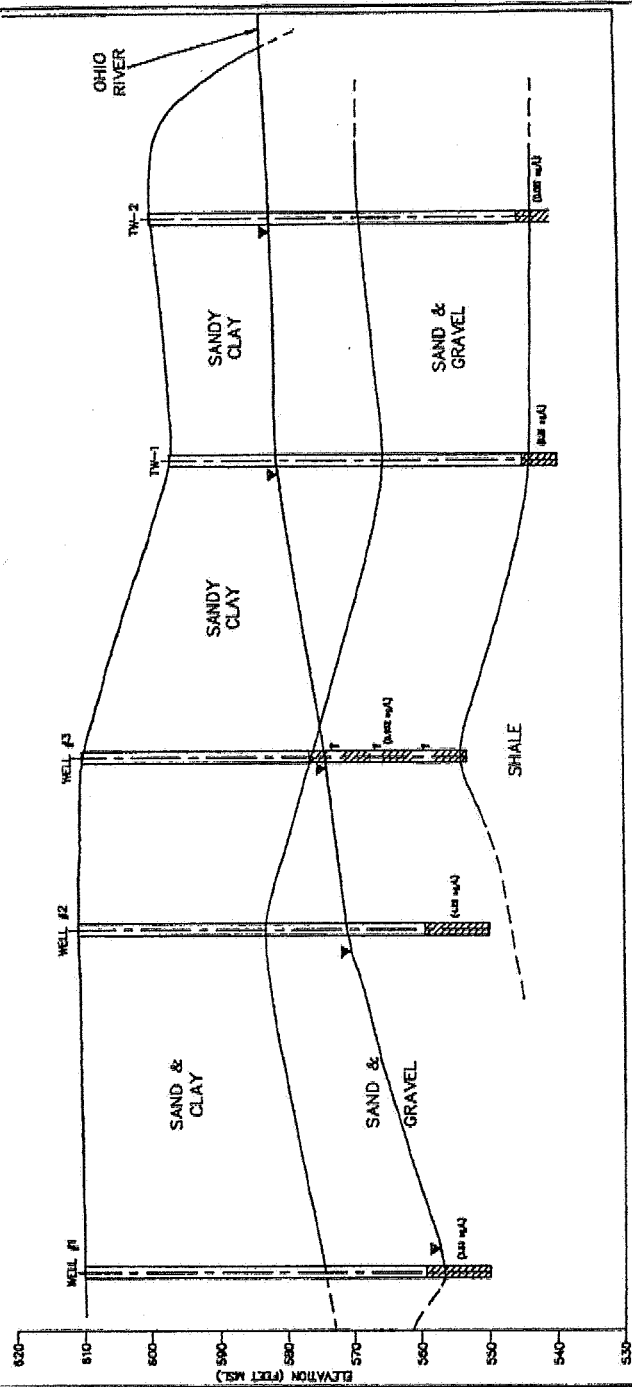
[illegible]

Horizontal Scale: $1'' = 60'$
Vertical Scale: $1'' = 10'$

[illegible]

SOUTH
B'

NORTH
B



Horizontal Scale 1" = 80'
Vertical Scale 1" = 10'

LEGEND:

- SCREENED INTERVAL IN TEST WELL OR PRODUCTION WELL AND C-2 CONCENTRATION IN GROUNDWATER (NO-CLDI $\mu\text{g/L}$)
- ESTIMATED SCREENED INTERVAL IN TEST WELL OR PRODUCTION WELL AND C-2 CONCENTRATION IN GROUNDWATER (NO-CLDI $\mu\text{g/L}$)
- GROUNDWATER ELEVATION

CROSS-SECTION B-B'

Corporate Remediation Group
An Atlantic Richfield Company
2000 West 10th Street
Birmingham, Alabama 35202-2027

Little Hoeking Water Association
Little Hoeking, Ohio

DATE	10/12/00	BY	12
REVISION			

