DOCUMENTATION OF ENVIRONMENTAL INDICATOR DETERMINATION
Interim Final 2/5/99
RCRA Corrective Action
Environmental Indicator (EI) RCRIS code (CA750)
Migration of Contaminated Groundwater Under Control

Facility Name:	Hercules Incorporated Research Center
Facility Address:	500 Hercules Road, Wilmington, Delaware 19808-1599
Facility EPA ID #:	DED001315647

1. Has all available relevant/significant information on known and reasonably suspected releases to the groundwater media, subject to RCRA Corrective Action (e.g., from Solid Waste Management Units (SWMU), Regulated Units (RU), and Areas of Concern (AOC)), been considered in this EI determination?

 ___X___ If yes - check here and continue with #2 below.
 ________ If no - re-evaluate existing data, or
 ________ if data are not available skip to #6 and enter "IN" (more information needed) status code.

BACKGROUND
Definition of Environmental Indicators (for the RCRA Corrective Action)

Environmental Indicators (EI) are measures being used by the RCRA Corrective Action program to go beyond programmatic activity measures (e.g., reports received and approved, etc.) to track changes in the quality of the environment. The two EI developed to-date indicate the quality of the environment in relation to current human exposures to contamination and the migration of contaminated groundwater. An EI for non-human (ecological) receptors is intended to be developed in the future.

Definition of "Migration of Contaminated Groundwater Under Control" EI

A positive "Migration of Contaminated Groundwater Under Control" EI determination ("YE" status code) indicates that the migration of "contaminated" groundwater has stabilized, and that monitoring will be conducted to confirm that contaminated groundwater remains within the original "area of contaminated groundwater" (for all groundwater "contamination" subject to RCRA corrective action at or from the identified facility (i.e., site-wide)).

Relationship of EI to Final Remedies

While Final remedies remain the long-term objective of the RCRA Corrective Action program the EI are near-term objectives which are currently being used as Program measures for the Government Performance and Results Act of 1993, GPRA). The "Migration of Contaminated Groundwater Under Control" EI pertains ONLY to the physical migration (i.e., further spread) of contaminated ground water and contaminants within groundwater (e.g., nonaqueous phase liquids or NAPLs). Achieving this EI does not substitute for achieving other stabilization or final remedy requirements and expectations associated with sources of contamination and the need to restore, wherever practicable, contaminated groundwater to be suitable for its designated current and future uses.

Duration / Applicability of EI Determinations

EI Determinations status codes should remain in RCRIS national database ONLY as long as they remain true (i.e., RCRIS status codes must be changed when the regulatory authorities become aware of contrary information).

2. Is groundwater known or reasonably suspected to be "contaminated"[1] above appropriately protective "levels" (i.e., applicable promulgated standards, as well as other appropriate standards, guidelines, guidance, or criteria) from releases subject to RCRA Corrective Action, anywhere at, or from, the facility?

__X__ If yes - continue after identifying key contaminants, citing appropriate "levels," and referencing supporting documentation.

_____ If no - skip to #8 and enter "YE" status code, after citing appropriate "levels," and referencing supporting documentation to demonstrate that groundwater is not "contaminated."

_____ If unknown - skip to #8 and enter "IN" status code.

Rationale and Reference(s):

The following information on ground water quality at the Hercules Research Center (the facility) has been excerpted from the Verification Investigation and Focused RCRA Facility Investigation Report, Hercules Research Center, dated 2 April 1993; the RCRA Facility Investigation Report, Hercules Research Center, dated 4 April 1997; and from three rounds of ground water data collected in 2005, 2006, and 2007 as part of the Phase II RFI that is still in progress.

Several shallow overburden wells were installed at the SWMUs and AOCs at the facility and sampled during the RCRA Verification Investigation (VI) and RCRA Facility Investigation (RFI) to evaluate ground water quality. Additional overburden and bedrock monitoring wells were installed during the Phase II RFI and were sampled in May and November 2005. Creek piezometers were also installed along the west bank of Red Clay Creek at five locations and sampled in November 2005 and February 2006. The creek piezometers and selected monitoring wells were also sampled in February 2007. Several compounds were detected in the ground water in both the overburden and in the bedrock ground water above USEPA Region III Risk Based Concentrations (RBC) for tap water and USEPA Maximum Contaminant Levels (MCL) for drinking water. The following briefly summarizes the ground water quality based on the available data to date.

Based on the 2005 data, shallow ground water beneath SWMU 4 contained primarily benzene and chlorobenzene above MCLs. Tetrachloroethene, alpha-BHC, beta-BHC, delta-BHC and aldrin exceeded their RBCs. In 1997, vinyl chloride, cis-1,2-dichloroethene, and several metals were detected but were either not detected or were below MCLs/RBCs in 2005.

AOC E ground water contained Tetrachloroethene (PCE), cis-1,2-dichloroethene (cis-1,2-DCE), benzene, trichloroethene (TCE), and vinyl chloride above MCLs based on the 2005 analytical data. Several pesticides (aldrin, alpha-BHC, beta-BHC, DDD, DDE, DDT and Dieldrin), PCBs (Aroclors 1254 and 1260) and PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, chrysene and ideno(1,2,3-cd)pyrene were present in 1997 but decreased to below detection limits in the 2005 sampling.

SWMU 9D ground water contained Endosulfan I but was below its RBC. Aldrin and several elevated metals were detected in 1997 but were either not detected or were below RBCs/MCLs in 2005.

SWMU 12 contained an elevated concentration of alpha-BHC in 1997, but had dropped to below detection limits in the 2005 sampling.

AOC B contained elevated concentrations of benzene, chlorobenzene, vinyl chloride, Aroclor 1260 and several pesticides and metals in 1997. By 2005, only benzene exceeded its MCL; although, chlorobenzene and 4,4-DDD exceeded their RBCs.

VOCs (including chlorinated VOCs and benzene), SVOCs (including some PAHs and 1,2,4-trichlorobenzene) and pesticides are present in shallow ground water adjacent to Red Clay Creek. The concentrations of these compounds are less than 10 times their respective MCL, based on data from five creek piezometers installed in 2005 and sampled in 2006 and 2007. One piezometer, CP-5, did not have any organic detections or inorganic parameters above MCLs. Mass balance dilution calculations of the ground water/surface water discharge rates indicated the VOCs, SVOCs, and pesticides are expected to be below the Delaware Surface Water Quality Standards (DSWQS).

In 1997, ground water samples from 4 of the 11 bedrock production wells that are used to supply drinking water to the facility were found to contain several VOCs, including benzene, carbon tetrachloride, chlorobenzene, chloroform, 1,2-dichloroethene, PCE, TCE and vinyl chloride. Of these, 1,2-dichloroethene, TCE, and PCE were present in the highest concentrations. By 2005, only PCE and TCE were above their MCLs; although, cis,1-2,DCE, chloroform, indeno (1,2,3-cd)pyrene, benzo(k)fluoranthene and 4,4-DDD were also detected. Periodic sampling by the Health Department indicates that the VOCs are below detection limits in tap samples.

Footnotes:

[1]"Contamination" and "contaminated" describes media containing contaminants (in any form, NAPL and/or dissolved, vapors, or solids, that are subject to RCRA) in concentrations in excess of appropriate "levels" (appropriate for the protection of the groundwater resource and its beneficial uses).

3. Has the **migration** of contaminated groundwater **stabilized** (such that contaminated groundwater is expected to remain within "existing area of contaminated groundwater"[2] as defined by the monitoring locations designated at the time of this determination)?

__X__ If yes - continue, after presenting or referencing the physical evidence (e.g., groundwater sampling/measurement/migration barrier data) and rationale why contaminated groundwater is expected to remain within the (horizontal or vertical) dimensions of the "existing area of groundwater contamination"[2]).

_____ If no (contaminated groundwater is observed or expected to migrate beyond the designated locations defining the "existing area of groundwater contamination"[2]) - skip to #8 and enter "NO" status code, after providing an explanation.

_____ If unknown - skip to #8 and enter "IN" status code.

Rationale and Reference(s):

Ground water in both the shallow overburden and in the bedrock aquifer is expected to flow toward and discharge into Red Clay Creek, based on the preliminary data collected during the Phase II RFI. Red Clay Creek is located along the facility's eastern property boundary. Although contaminated ground water may discharge into Red Clay Creek, the steep topography east of the creek would likely cause ground water east of the creek to flow westward toward the creek in the direction of the facility. This opposite ground water flow direction likely prevents migration of ground water beyond the creek and thus prevents off-site migration of ground water in the aquifer.

[2] "existing area of contaminated groundwater" is an area (with horizontal and vertical dimensions) that has been verifiably demonstrated to contain all relevant groundwater contamination for this determination, and is defined by designated (monitoring) locations proximate to the outer perimeter of "contamination" that can and will be sampled/tested in the future to physically verify that all "contaminated" groundwater remains within this area, and that the further migration of "contaminated" groundwater is not occurring. Reasonable allowances in the proximity of the monitoring locations are permissible to incorporate formal remedy decisions (i.e., including public participation) allowing a limited area for natural attenuation.

4. Does "contaminated" groundwater discharge into surface water bodies?

__X_ If yes - continue after identifying potentially affected surface water bodies.
_____ If no - skip to #7 (and enter a "YE" status code in #8, if #7 = yes) after providing an explanation and/or referencing documentation supporting that groundwater "contamination" does not enter surface water bodies.
_____ If unknown - skip to #8 and enter "IN" status code.

Rationale and Reference(s):

During the Phase I RFI, ground water in the overburden was demonstrated to flow toward Red Clay Creek. Hydraulic data collected during the Phase II RFI confirmed the flow direction in the overburden and in the bedrock aquifer. Overburden wells and piezometers located adjacent to the creek contain some VOCs, SVOCs, and pesticides above MCLs.

5. Is the discharge of "contaminated" groundwater into surface water likely to be "insignificant" (i.e., the maximum concentration[3] of each contaminant discharging into surface water is less than 10 times their appropriate groundwater "level," and there are no other conditions (e.g., the nature, and number, of discharging contaminants, or environmental setting), which significantly increase the potential for unacceptable impacts to surface water, sediments, or eco-systems at these concentrations)?

__X__ If yes - skip to #7 (and enter "YE" status code in #8 if #7 = yes), after documenting: 1) the maximum known or reasonably suspected concentration[3] of key contaminants discharged above their groundwater "level," the value of the appropriate "level(s)," and if there is evidence that the concentrations are increasing; and 2) provide a statement of professional judgment/explanation (or reference documentation) supporting that the discharge of groundwater contaminants into the surface water is not anticipated to have unacceptable impacts to the receiving surface water, sediments, or eco-system.

_____ If no - (the discharge of "contaminated" groundwater into surface water is potentially significant) - continue after documenting: 1) the maximum known or reasonably suspected concentration[3] of each contaminant discharged above its groundwater "level," the value of the appropriate "level(s)," and if there is evidence that the concentrations are increasing; and 2) for any contaminants discharging into surface water in concentrations[3] greater than 100 times their appropriate groundwater "levels," the estimated total amount (mass in kg/yr) of each of these contaminants that are being discharged (loaded) into the surface water body (at the time of the determination), and identify if there is evidence that the amount of discharging contaminants is increasing.

_____ If unknown - enter "IN" status code in #8.

Rationale and Reference(s):

The concentrations of compounds in shallow ground water immediately adjacent to Red Clay Creek are less than 10 times their respective MCL, based on the most recent analytical data from the five creek piezometers (CP-1 through CP-5) and wells MW-12, MW-13, SWMU-4/MW-2 and SWMU-4/MW-3. These concentrations are expected to decrease as the ground water discharges into Red Clay Creek due to dilution and volatilization and are not anticipated to unacceptably impact the surface water or sediments of the creek. The ground water in the above wells and piezometers immediately adjacent to the creek have the following maximum concentrations, based on the most recent analytical data. One piezometer, CP-5, did not have any organic detections or inorganic parameters above MCLs.

Parameter	Concentration (ug/l)	Parameter	Concentration (ug/l)
chlorobenzene	120	chloroform	0.66
cis-1,2-DCE	150	2-chlorophenol	1.1
TCE	27	acenaphthene	0.63
1,4-dichlorobenzene	31	1,2,4-trichlorobenzene	0.81
1,2- dichlorobenzene	15	4,4-DDD	5.1
PCE	11	alpha-BHC	0.34
vinyl chloride	8.2	beta-BHC	0.41
benzene	4.8	heptachlor	0.039
trans-1,2-DCE	1.8	4,4-DDE	0.082

To further evaluate the concentrations of these compounds at discharge into Red Clay Creek, Hercules performed mass balance dilution calculations using both the highest detected ground water concentration and the average concentration of the above compounds and compared the resultant surface water concentrations to the Delaware Surface Water Quality Standards (DSWQS). To perform the mass balance dilution calculations, Hercules calculated the ground water discharge rate into Red Clay Creek at each area along the creek where the individual contaminants were detected in monitoring wells or creek piezometers. This discharge rate was compared to the average low flow discharge of Red Clay Creek during the months of June, July, and August, using stream gaging data published by the U.S. Geological Survey. Slug tests were performed in the eight wells and piezometers listed above to calculate an average hydraulic conductivity for the aquifer in the vicinity of the creek (see Attachment 1). The ground water discharge rate into Red Clay Creek was then calculated, assuming Darcian flow conditions, using this average hydraulic conductivity, the saturated thickness of the aquifer based on monitoring well data, and the length along Red Clay Creek where each compound was present, using the most recent analytical data for VOCs, SVOCs, and pesticides.

First, the highest detected concentration of each parameter in ground water adjacent to the creek was multiplied by the ground water/surface water dilution factor to calculate the highest concentration of that parameter that would be expected to be present in Red Clay Creek under low-flow stream conditions. This approach assumes the same high concentration of a given contaminant is uniformly discharging to Red Clay Creek from all the wells where it was detected. The calculated surface water concentrations were then compared to the DSWQS for human carcinogens (assuming fish and water ingestion). Based on the most recent ground water analytical data for VOCs, SVOCs, and pesticides, the highest calculated surface water concentrations in Red Clay Creek were all below the DSWQS, except for 4,4-DDD which had a marginal exceedance. Using the highest detected concentration of each parameter along with the average low stream flow is a very conservative approach to evaluate worst-case concentrations during periods of low flow in Red Clay Creek. Surface water concentrations are expected to be lower during higher stream flow periods due to greater dilution and will likely result in 4,4-DDD being below the DSWQS during those times. In addition, unfiltered results for the pesticide analyses were used to calculate the worst-case high concentrations. Filtered pesticide analyses, which were also collected, were all below quantitation limits and suggest pesticides may not be discharging to Red Clay Creek because they are likely adsorbing to the aquifer matrix. Please see Table 1 for a summary of the dilution factors and the calculated surface water concentrations. The well locations of each detected parameter along with the length of the creek segment where these parameters would discharge are summarized on Table 2.

In addition to using the highest concentrations, the average concentration for each parameter in ground water was also calculated to estimate the average concentrations expected to be present in Red Clay Creek. Although not as conservative, using the average concentration represents a more likely discharge scenario. Each average ground water concentration was then multiplied by the ground water/surface water dilution factor to calculate the average parameter concentration expected to be present in Red Clay Creek under low flow stream conditions. The calculated surface water concentrations were then compared to the DSWQS for human carcinogens (assuming fish and water ingestion). Based on the most recent ground water analytical data, the average surface water concentrations in Red Clay Creek were all below the DSWQS and are likely to be insignificant. Please see Table 3 for a summary of the dilution factors and the average surface water concentrations. USGS discharge data for Red Clay Creek for the years 2001 through 2005, along with the average low-flow calculations, are summarized on Table 4.

---

3 As measured in groundwater prior to entry to the groundwater-surface water/sediment interaction (e.g., hyporheic) zone.

6. Can the discharge of "contaminated" groundwater into surface water be shown to be "currently acceptable" (i.e., not cause impacts to surface water, sediments or eco-systems that should not be allowed to continue until a final remedy decision can be made and implemented[4])?

_____ If yes - continue after either: 1) identifying the Final Remedy decision incorporating these conditions, or other site-specific criteria (developed for the protection of the site's surface water, sediments, and eco-systems), and referencing supporting documentation demonstrating that these criteria are not exceeded by the discharging groundwater; OR.
2) providing or referencing an interim-assessment,[5] appropriate to the potential for impact, that shows the discharge of groundwater contaminants into the surface water is (in the opinion of a trained specialists, including ecologist) adequately protective of receiving surface water, sediments, and eco-systems, until such time when a full assessment and final remedy decision can be made. Factors which should be considered in the interim-assessment (where appropriate to help identify the impact associated with discharging groundwater) include: surface water body size, flow, use/classification/habitats and contaminant loading limits, other sources of surface water/sediment contamination, surface water and sediment sample results and comparisons to available and appropriate surface water and sediment "levels," as well as any other factors, such as effects on ecological receptors (e.g., via bio-assays/benthic surveys or site-specific ecological Risk Assessments), that the overseeing regulatory agency would deem appropriate for making the EI determination.

_____ If no - (the discharge of "contaminated" groundwater can not be shown to be "currently acceptable") - skip to #8 and enter "NO" status code, after documenting the currently unacceptable impacts to the surface water body, sediments, and/or eco-systems.

_____ If unknown - skip to 8 and enter "IN" status code.

Rationale and Reference(s):

[4] Note, because areas of inflowing groundwater can be critical habitats (e.g., nurseries or thermal refugia) for many species, appropriate specialist (e.g., ecologist) should be included in management decisions that could eliminate these areas by significantly altering or reversing groundwater flow pathways near surface water bodies.

[5] The understanding of the impacts of contaminated groundwater discharges into surface water bodies is a rapidly developing field and reviewers are encouraged to look to the latest guidance for the appropriate methods and scale of demonstration to be reasonably certain that discharges are not causing currently unacceptable impacts to the surface waters, sediments or eco-systems.

7. Will groundwater monitoring / measurement data (and surface water/sediment/ecological data, as necessary) be collected in the future to verify that contaminated groundwater has remained within the horizontal (or vertical, as necessary) dimensions of the "existing area of contaminated groundwater?"

__X__ If yes - continue after providing or citing documentation for planned activities or future sampling/measurement events. Specifically identify the well/measurement locations which will be tested in the future to verify the expectation (identified in #3) that groundwater contamination will not be migrating horizontally (or vertically, as necessary) beyond the "existing area of groundwater contamination."
______ If no - enter "NO" status code in #8.
______ If unknown - enter "IN" status code in #8.

Rationale and Reference(s):

Currently, five monitoring wells that monitor ground water quality at SWMU 9A/15 are sampled semi-annually as part of the Post-Closure Care Requirements for that SWMU. If required, potential additional periodic ground water monitoring may be performed as part of Post-Closure Care monitoring for other SWMUs that may undergo corrective action. Such periodic monitoring may involve the sampling of additional wells and wells and creek piezometers along Red Clay Creek, if required.

8. Check the appropriate RCRIS status codes for the Migration of Contaminated Groundwater Under Control EI (event code CA750), and obtain Supervisor (or appropriate Manager) signature and date on the EI determination below (attach appropriate supporting documentation as well as a map of the facility).

__X__ YE - Yes, "Migration of Contaminated Groundwater Under Control" has been verified. Based on a review of the information contained in this EI determination, it has been determined that the "Migration of Contaminated Groundwater" is "Under Control" at the Hercules Research Center facility , EPA ID # DED001315647, located at 500 Hercules Road, Wilmington, Delaware 19808. Specifically, this determination indicates that the migration of "contaminated" groundwater is under control, and that monitoring will be conducted to confirm that contaminated groundwater remains within the "existing area of contaminated groundwater" This determination will be re-evaluated when the Agency becomes aware of significant changes at the facility.

_____ NO - Unacceptable migration of contaminated groundwater is observed or expected.

_____ IN - More information is needed to make a decision.

Prepared by Russell D. Devan, P.G., ERM Project Manager

Approved by	[signature]	Date	9/26/07
	Michael J. Macheska II		
	Environmental Scientist		

Supervised by	[signature]	Date	9/26/07
	Nancy C. Marker		
	Environmental Program Manager II		

Locations where References may be found:

Hercules Research Center RCRA Facility Investigation Report, 4 April 1997
Phase II RFI Progress Report for Hercules Research Center, dated 30 May 2006
Phase II RFI Progress Report for Hercules Research Center, dated 28 July 2006
Phase II RFI Progress Report for Hercules Research Center, dated 29 March 2007

Contact telephone and e-mail numbers:

Michael Macheska
DNREC Solid and Hazardous Waste Management Branch
302-739-9403
Michael.Macheska@state.de.us

John Hoffman
Hercules Incorporated
302-995-3233
jhoffman@herc.com

Table 1
Ground Water/Surface Water Dilution Factors and Anticipated Maximum Contaminant Concentrations in Surface Water
Hercules Research Center
Wilmington, Delaware

Compound of Concern	Ground Water Flow Calculation K	i	L	H	A	Qgw	Dilution Factor Qrcc	DF	Location of Max Concentration	Maximum Concentration* Cgw (ug/l)	Csw (ug/l)	Delaware SWQC (ug/l)
Vinyl Chloride	3	0.025	445	14	6230	467.25	5670720	0.0000824	CP-2	8.2	0.000676	0.025
trans-1,2-dichloroethene	3	0.025	225	14	3150	236.25	5670720	0.0000417	CP-2	1.8	0.000075	NA
chloroform	3	0.025	390	14	5460	409.5	5670720	0.0000722	CP-3	0.66	0.000048	NA
TCE	3	0.025	520	14	7280	546	5670720	0.0000963	CP-2	27	0.002600	2.5
benzene	3	0.025	460	14	6440	483	5670720	0.0000852	CP-4	4.8	0.000409	0.61
cis-1,2-dichloroethene	3	0.025	520	14	7280	546	5670720	0.0000963	CP-2	150	0.014443	NA
PCE	3	0.025	520	14	7280	546	5670720	0.0000963	CP-3	11	0.001059	0.69
chlorobenzene	3	0.025	740	14	10360	777	5670720	0.0001370	CP-4	120	0.016442	NA
2-chlorophenol	3	0.025	290	14	4060	304.5	5670720	0.0000537	CP-4	1.1	0.000059	NA
1,4-dichlorobenzene	3	0.025	390	14	5460	409.5	5670720	0.0000722	CP-3	31	0.002239	NA
1,2-dichlorobenzene	3	0.025	390	14	5460	409.5	5670720	0.0000722	CP-3	15	0.001083	NA
1,2,4-trichlorobenzene	3	0.025	300	14	4200	315	5670720	0.0000555	CP-3	0.81	0.000045	NA
acenaphthene	3	0.025	290	14	4060	304.5	5670720	0.0000537	CP-4	0.63	0.000034	NA
4,4'-DDE	3	0.025	460	14	6440	483	5670720	0.0000852	CP-4	0.082	0.000007	0.00022
4,4'-DDD	3	0.025	390	14	5460	409.5	5670720	0.0000722	CP-3	5.1	0.000368	0.00022
alpha-BHC	3	0.025	300	14	4200	315	5670720	0.0000555	CP-3	0.34	0.000019	0.0026
beta-BHC	3	0.025	370	14	5180	388.5	5670720	0.0000685	CP-3	0.41	0.000028	0.0091
Heptachlor	3	0.025	290	14	4060	304.5	5670720	0.0000537	CP-4	0.039	0.000002	0.000079

Notes:
K = Average Measured Hydraulic Conductivity in feet per day (ft/day)
i = Average Measured Hydraulic Gradient
A = Area of Groundwater Flow in square feet (L X H)
L = Length area along Red Clay Creek where a compound is present (ft)
see Table 2 for backup calculations.
H = Saturated thickness above bedrock (ft)
Qgw = Groundwater Flow in cubic feet per day into Red Clay Creek Cubic Feet per Day (CFD)
DF = Dilution factor (Qgw/Qrcc)
Qrcc = Qrcc flow of Red Clay Creek taken from published USGS gaging data CFD
see Table 4 for USGS gaging data average low flow calculations
Cgw = Maximum concentration of the pesticide in ground water adjacent to the stream in ug/l
Csw = Concentration of the pesticide in surface water after mixing ug/l (Cgw X DF)
Shaded area = maximum concentration of parameter in surface water exceeds Delaware SWQC
*Based on the most recent analytical results for each parameter and well/piezometer.

Slug Test Hydraulic Conductivity (Feet Per Day)

CP-1	0.9
CP-2	0.6
CP-3	7.1
CP-4	6.7
MW-12	Data Could Not Be Analyzed
MW-13	4.5
SWMU4 MW-2	0.7
SWMU4 MW-3	0.4
Average	**3.0**

Table 2
Length of Creek Segment Where Contaminants Are Present in Ground Water
Hercules Research Center
Wilmington, Delaware

Parameter	Well Locations of Detected Parameter	Length of Creek Segment Between Wells (ft)
Vinyl Chloride	CP-1 to CP-4	445
trans-1,2-dichloroethene	CP-1 to CP-3	225
chloroform	MW-13 to CP-4	390
TCE	MW-12 to CP-4	520
benzene	MW-13 to SWMU 4/MW-3	460
cis-1,2-dichloroethene	MW-12 to CP-4	520
PCE	MW-12 to CP-4	520
chlorobenzene	CP-1 to CP-5	740
2-chlorophenol	CP-3 to SWMU 4/MW-3	290
1,4-dichlorobenzene	MW-13 to CP-4	390
1,2-dichlorobenzene	MW-13 to CP-4	390
1,2,4-trichlorobenzene	CP-2 to CP-4	300
acenaphthene	CP-3 to SWMU 4/MW-3	290
4,4'-DDE	MW-13 to SWMU 4/MW-3	460
4,4'-DDD	MW-13 to CP-4	390
alpha-BHC	CP-2 to CP-4	300
beta-BHC	CP-2 to SWMU 4/MW-3	370
Heptachlor	CP-3 to SWMU 4/MW-3	290

Table 3
Ground Water/Surface Water Dilution Factors and Anticipated Average Contaminant Concentrations in Surface Water
Hercules Research Center
Wilmington, Delaware

	Ground Water Flow Calculation						Dilution Factor		Average Concentration*		Delaware
Compound of Concern	K	i	L	H	A	Qgw	Qrcc	DF	Cgw (ug/l)	Csw (ug/l)	SWQC (ug/l)
Vinyl Chloride	3	0.025	445	14	6230	467.25	5670720	0.0000824	3.1	0.000255	0.025
trans-1,2-dichloroethene	3	0.025	225	14	3150	236.25	5670720	0.0000417	1	0.000042	NA
chloroform	3	0.025	390	14	5460	409.5	5670720	0.0000722	0.43	0.000031	NA
TCE	3	0.025	520	14	7280	546	5670720	0.0000963	8.3	0.000799	2.5
benzene	3	0.025	460	14	6440	483	5670720	0.0000852	1.4	0.000119	0.61
cis-1,2-dichloroethene	3	0.025	520	14	7280	546	5670720	0.0000963	37.2	0.003582	NA
PCE	3	0.025	520	14	7280	546	5670720	0.0000963	3.8	0.000366	0.69
chlorobenzene	3	0.025	740	14	10360	777	5670720	0.0001370	42.4	0.005810	NA
2-chlorophenol	3	0.025	290	14	4060	304.5	5670720	0.0000537	0.6	0.000032	NA
1,4-dichlorobenzene	3	0.025	390	14	5460	409.5	5670720	0.0000722	8.3	0.000599	NA
1,2-dichlorobenzene	3	0.025	390	14	5460	409.5	5670720	0.0000722	4.3	0.000311	NA
1,2,4-trichlorobenzene	3	0.025	300	14	4200	315	5670720	0.0000555	0.44	0.000024	NA
acenaphthene	3	0.025	290	14	4060	304.5	5670720	0.0000537	0.43	0.000023	NA
4,4'-DDE	3	0.025	460	14	6440	483	5670720	0.0000852	0.034	0.000003	0.00022
4,4'-DDD	3	0.025	390	14	5460	409.5	5670720	0.0000722	1.31	0.000095	0.00022
alpha-BHC	3	0.025	300	14	4200	315	5670720	0.0000555	0.12	0.000007	0.0026
beta-BHC	3	0.025	370	14	5180	388.5	5670720	0.0000685	0.12	0.000008	0.0091
Heptachlor	3	0.025	290	14	4060	304.5	5670720	0.0000537	0.02	0.000001	0.000079

<u>Notes:</u>
K = Average Measured Hydraulic Conductivity in feet per day (ft/day)
i = Average Measured Hydraulic Gradient
A = Area of Ground water Flow in square feet (L X H)
L = Length of area along Red Clay Creek where a compound is present (ft)
H = Saturated thickness above bedrock (ft)
Qgw = Ground water Flow in cubic feet per day into Red Clay Creek Cubic Feet per Day (CFD)
calculated using Darcy's Law (Q=KiA)
DF = Dilution factor (Qgw/Qrcc)
Qrcc = Average flow of Red Clay Creek during June, July, and August from 2001 through 2005, from published USGS gaging data (CFD)
Cgw = Average concentration in ground water adjacent to the stream in micrograms per liter (ug/l)
Csw = Concentration of the pesticide in surface water after mixing ug/l (Cgw X DF)
*Based on most recent analytical results for each parameter and well/piezometer.

Hydraulic Conductivity Summary (feet/day)

CP-1	0.9
CP-2	0.6
CP-3	7.1
CP-4	6.7
MW-12	Data Could Not Be Analyzed
MW-13	4.5
SWMU4 MW-	0.7
SWMU4 MW-	0.4
Average	**3.0**

Table 4
Red Clay Creek Discharge Data
Hercules Research Center
Wilmington, Delaware

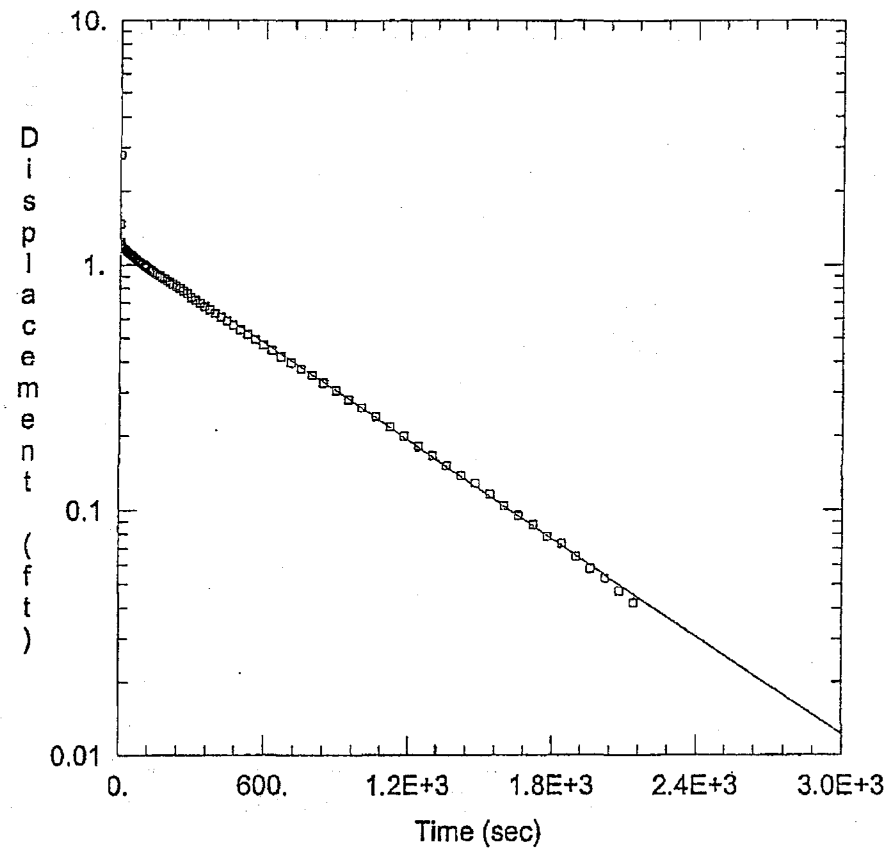
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	69.8	71	84.3	63.2	56.7	60.3	29.3	28.4	26.6	18.8	20.1	24.7
2002	35.2	24.4	45.7	31.6	36.2	37.9	13.9	19.8	15.1	40	57.3	98.6
2003	58.9	129.4	179.7	86	68.7	192.8	57.3	68.6	326.6	134.4	125.3	188.4
2004	86.3	166.9	88.4	120.5	91.2	99.4	124.1	129.7	204.5	88.1	135.7	125.2
2005	122.2	101.4	131.4	161.6	71.5	48	48.7	26.3	22.8	80.4	45.9	75
Average	74.48	98.62	460	92.58	64.86	87.68	54.66	54.56	119.12	72.34	76.86	102.38

USGS 01480000 RED CLAY CREEK AT WOODDALE, DE
New Castle County, Delaware 740
Hydrologic Unit Code 02040205
Latitude 39°45'46.1", Longitude 75°38'11.4" NAD83
Drainage area 47.0 square miles
Gage datum 81.46 feet above sea level NGVD29
All data are in cubic feet/second (cfs)

Average Low Flow Discharge for Red Clay Creek

Date	Q (cfs)	370
June 2001-2005	87.68	
July 2001-2005	54.66	
August 2001-2005	54.56	
Avg. Low Flow (CFS)	65.63	
Avg. Low Flow (CFD)	5,670,720	

Attachment 1
Hydraulic Conductivity Calculations



WELL TEST ANALYSIS

Data Set: C:\...\CP-1.aqt
Date: 08/03/07 Time: 10:50:01

PROJECT INFORMATION

Company: Roux Associates Inc
Client: Hercules
Project: 01524J
Location: Research Center
Test Well: SWMU 4/MW-2
Test Date: 12/05

AQUIFER DATA

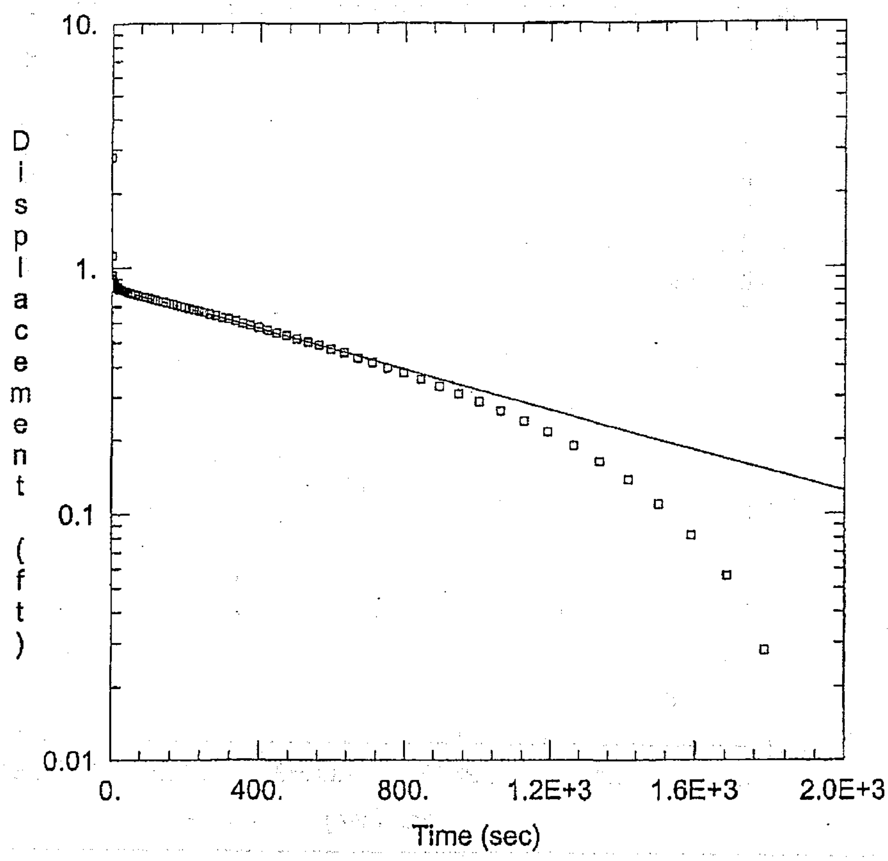
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (CP-1)

Initial Displacement: 2.8 ft
Total Well Penetration Depth: 8.9 ft
Casing Radius: 0.17 ft
Static Water Column Height: 4. ft
Screen Length: 5. ft
Wellbore Radius: 0.17 ft
Gravel Pack Porosity: 0.33

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.915 ft/day
y0 = 1.191 ft



WELL TEST ANALYSIS

Data Set: S:\JAL\HERC\Research Center\RFI\Slug tests\CP-2.aqt
Date: 08/03/07 Time: 12:01:02

PROJECT INFORMATION

Company: Roux Associates Inc
Client: Hercules
Project: 01524J
Location: Research Center
Test Well: SWMU 4/MW-2
Test Date: 12/05

AQUIFER DATA

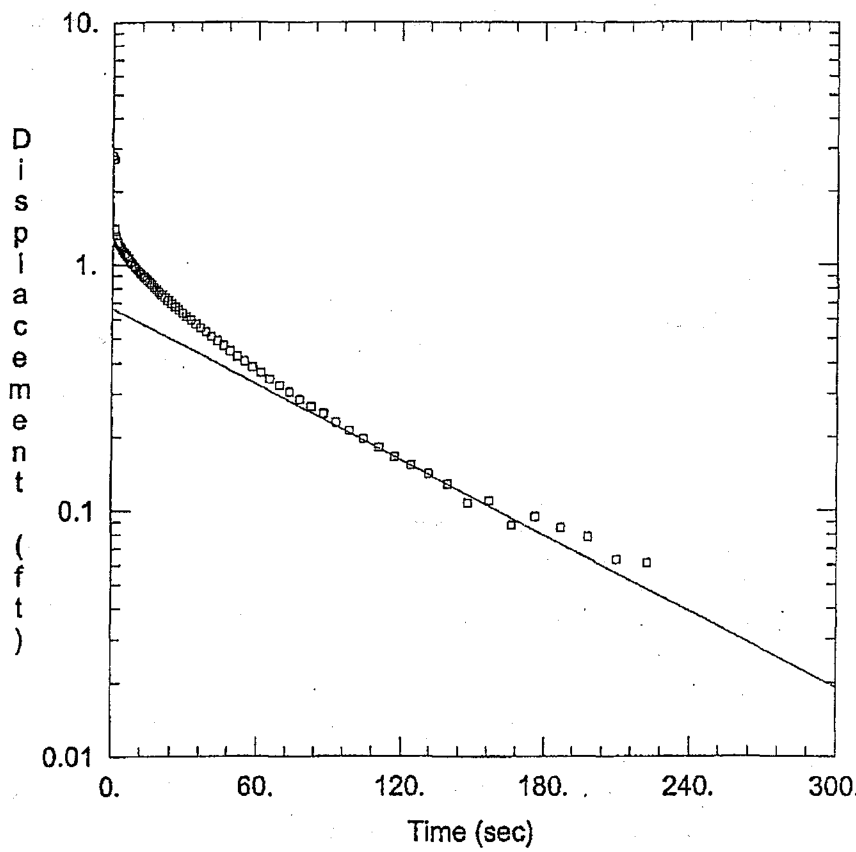
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (CP-2)

Initial Displacement: 2.8 ft
Total Well Penetration Depth: 9.7 ft
Casing Radius: 0.17 ft
Static Water Column Height: 4. ft
Screen Length: 5. ft
Wellbore Radius: 0.17 ft
Gravel Pack Porosity: 0.33

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.5805 ft/day
y0 = 0.8306 ft



WELL TEST ANALYSIS

Data Set: C:\...\CP-3.aqt
Date: 08/03/07 Time: 10:50:11

PROJECT INFORMATION

Company: Roux Associates Inc
Client: Hercules
Project: 01524J
Location: Research Center
Test Well: SWMU 4/MW-2
Test Date: 12/05

AQUIFER DATA

Saturated Thickness: 20. ft Anisotropy Ratio (Kz/Kr): 1.

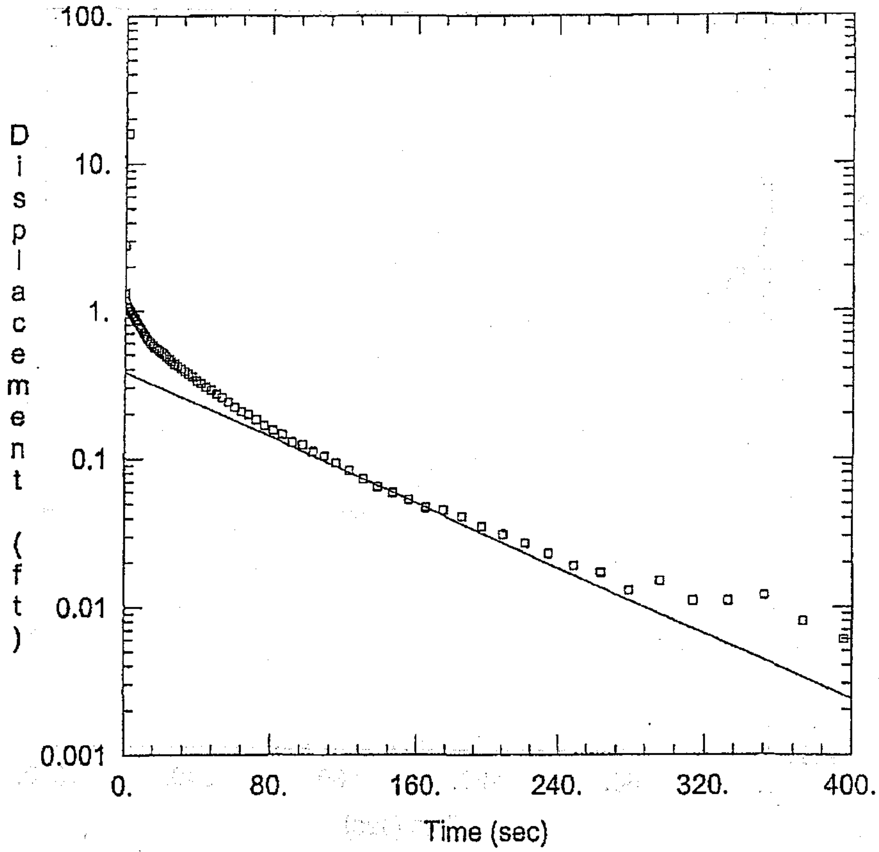
WELL DATA (CP-3)

Initial Displacement: 2.8 ft
Total Well Penetration Depth: 9.5 ft
Casing Radius: 0.17 ft
Static Water Column Height: 4. ft
Screen Length: 5. ft
Wellbore Radius: 0.17 ft
Gravel Pack Porosity: 0.33

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 7.182 ft/day y0 = 0.6637 ft



WELL TEST ANALYSIS

Data Set: C:\...\CP-4.aqt
Date: 08/03/07 Time: 10:50:24

PROJECT INFORMATION

Company: Roux Associates Inc
Client: Hercules
Project: 01524J
Location: Research Center
Test Well: SWMU 4/MW-2
Test Date: 12/05

AQUIFER DATA

Saturated Thickness: 15. ft Anisotropy Ratio (Kz/Kr): 1.

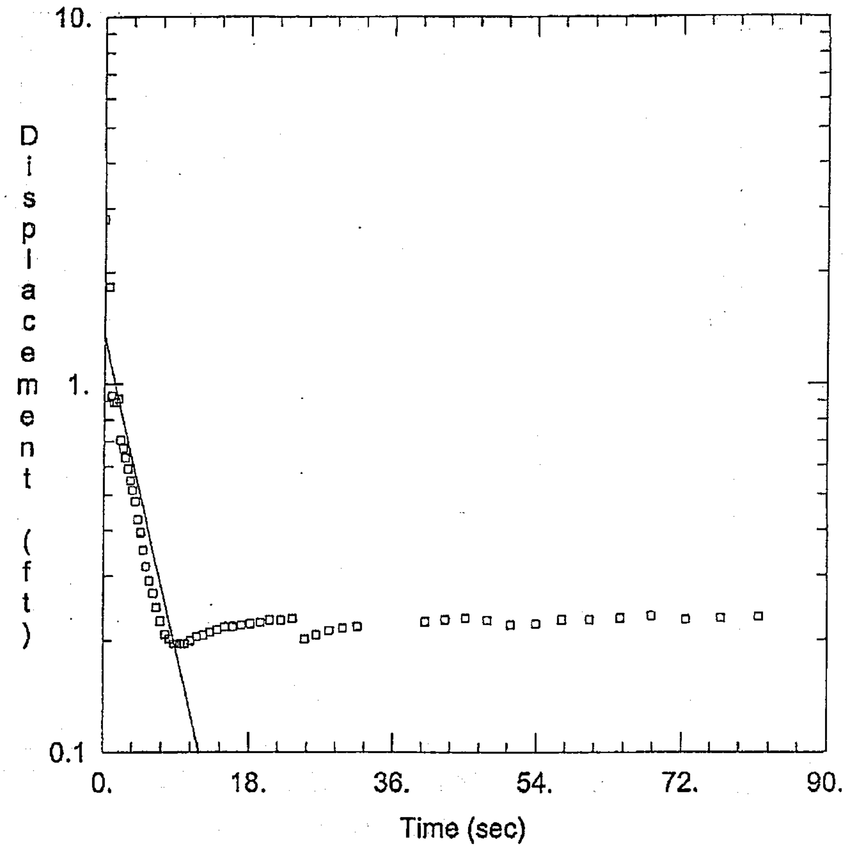
WELL DATA (CP-4)

Initial Displacement: 2.8 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.17 ft
Static Water Column Height: 4. ft
Screen Length: 5. ft
Wellbore Radius: 0.17 ft
Gravel Pack Porosity: 0.33

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 6.764 ft/day y0 = 0.3827 ft



WELL TEST ANALYSIS

Data Set: C:\...\MW-12.aqt
Date: 08/03/07
Time: 10:50:32

PROJECT INFORMATION

Company: Roux Associates Inc
Client: Hercules
Project: 01524J
Location: Research Center
Test Well: SWMU 4/MW-2
Test Date: 12/05

AQUIFER DATA

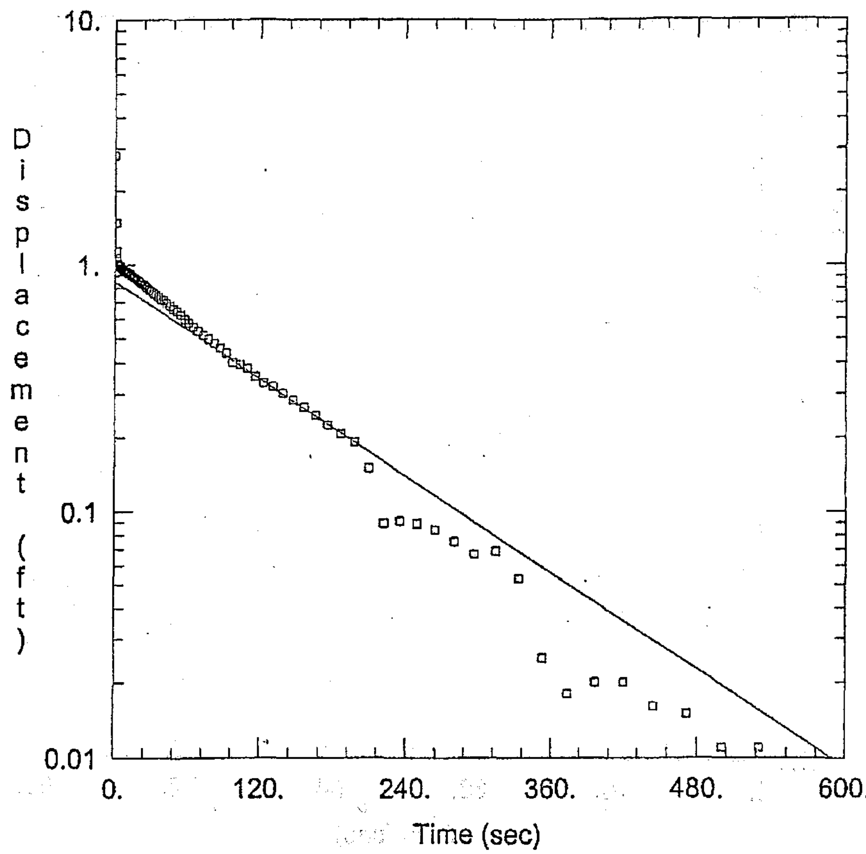
Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-12)

Initial Displacement: 2.8 ft
Total Well Penetration Depth: 15. ft
Casing Radius: 0.17 ft
Static Water Column Height: 4. ft
Screen Length: 10. ft
Wellbore Radius: 0.33 ft
Gravel Pack Porosity: 0.33

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 128.9 ft/day
y0 = 1.343 ft



WELL TEST ANALYSIS

Data Set: C:\...\MW-13.aqt
Date: 08/03/07 Time: 10:50:44

PROJECT INFORMATION

Company: Roux Associates Inc
Client: Hercules
Project: 01524J
Location: Research Center
Test Well: SWMU 4/MW-2
Test Date: 12/05

AQUIFER DATA

Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 1.

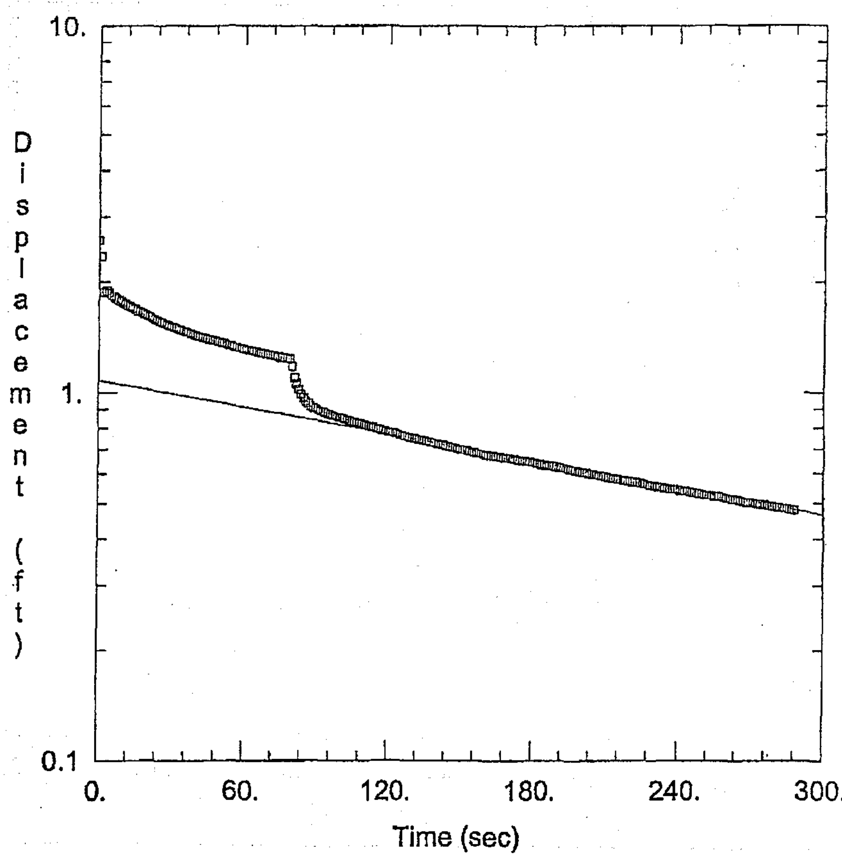
WELL DATA (MW-13)

Initial Displacement: 2.8 ft
Total Well Penetration Depth: 15. ft
Casing Radius: 0.17 ft
Static Water Column Height: 4. ft
Screen Length: 10. ft
Wellbore Radius: 0.33 ft
Gravel Pack Porosity: 0.33

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 4.458 ft/day
y0 = 0.8508 ft



WELL TEST ANALYSIS

Data Set: S:\JAL\HERC\Research Center\RFI\Slug tests\SWMU4MW2.aqt
Date: 08/03/07 Time: 12:03:29

PROJECT INFORMATION

Company: Roux Associates Inc
Client: Hercules
Project: 01524J
Location: Research Center
Test Well: SWMU 4/MW-2
Test Date: 12/05

AQUIFER DATA

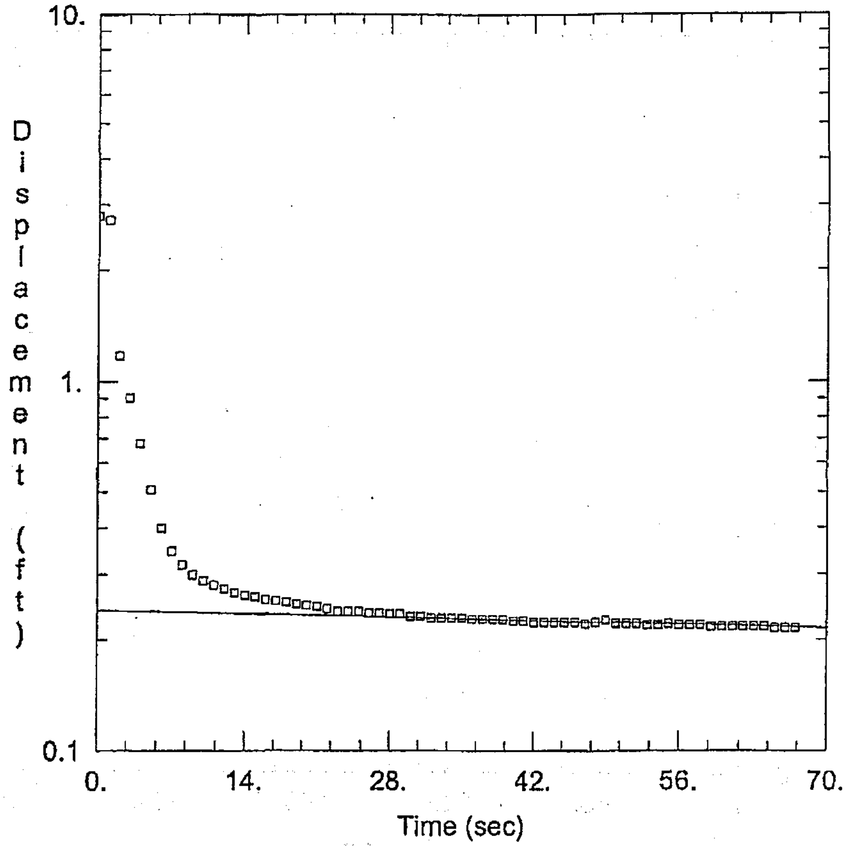
Saturated Thickness: 15. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (SWMU 4/MW-2)

Initial Displacement: 2.6 ft
Total Well Penetration Depth: 7. ft
Casing Radius: 0.17 ft
Static Water Column Height: 7. ft
Screen Length: 10. ft
Wellbore Radius: 0.33 ft
Gravel Pack Porosity: 0.33

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.727 ft/day
y0 = 1.081 ft



WELL TEST ANALYSIS

Data Set: C:\...\SWMU4MW3.aqt
Date: 08/03/07 Time: 10:51:06

PROJECT INFORMATION

Company: Roux Associates Inc
Client: Hercules
Project: 01524J
Location: Research Center
Test Well: SWMU 4/MW-2
Test Date: 12/05

AQUIFER DATA

Saturated Thickness: 20. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (SWMU 4/MW-3)

Initial Displacement: 2.8 ft
Total Well Penetration Depth: 4. ft
Casing Radius: 0.17 ft
Static Water Column Height: 4. ft
Screen Length: 8. ft
Wellbore Radius: 0.33 ft
Gravel Pack Porosity: 0.33

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice
K = 0.4124 ft/day y0 = 0.2404 ft

Attachment 2
Average Ground Water
Concentration Calculations

ATTACHMENT 2

Environmental Resources Management

ERM®

Proj, Phase, Task, Org 0015480.10 Sheet 1 of 5
Project Name Hercules Res. CTR. - ENV. Indicators
Subject Calculation of Average Parameter Concentration
By R. Devan Date 25 July 2007
Chkd by ______ Date ______

Vinyl chloride

wells	concentration (ug/l)
CP-1	0.92 u
MW-13	4
CP-2	8.2
CP-3	2.4
CP-4	0.92 u

Avg. Concentration

$$\frac{0.92/2 + 4 + 8.2 + 2.4 + 0.92/2}{5}$$

Avg Conc (C_{gw}) = 3.1 µg/l

Distance between wells (L) = 445 feet

trans-1,2-dichloroethene

wells	concentration (µg/L)
CP-3	0.8 u
CP-2	1.8
MW-13	1.4
CP-1	0.8 u

Avg. Conc. (C_{gw})

$$= \frac{\frac{0.8}{2} + 1.8 + 1.4 + \frac{0.8}{2}}{4} = 1.0\ \mu g/l$$

Distance Between Wells (L) = 225 feet

Chloroform

wells	concentration (µg/L)
CP-4	0.52 u
CP-3	0.66 J
CP-2	0.55 J
MW-13	0.52 u

Avg. concentration (C_{gw})

$$= \frac{\frac{0.52}{2} + 0.66 + 0.55 + \frac{0.52}{2}}{4}$$

= 0.43 µg/l

distance between wells (L) = 390 ft

Trichloroethene (TCE)

wells	Concentration (µg/l)
CP-4	0.71 u
CP-3	8.7
CP-2	27
MW-13	7
CP-1	5.4
MW-12	1.1

Avg concentration (C_{gw})

$$= \frac{\frac{0.71}{2} + 8.7 + 27 + 5.4 + 7 + 1.1}{6}$$

= 8.3 µg/l

distance between wells (L) = 520 ft

Environmental Resources Management

ERM

Proj, Phase, Task, Org 0015480.10 Sheet 2 of 5
Project Name Hercules Res. Ctr - Env. Indicators
Subject Calculation of Avg. Parameter Concentrations
By R Devan Date 25 July 2007
Chkd by ______ Date ______

Benzene

Wells	Concentration (ug/l)
SWMU 4/MW-3	0.54 U
CP-4	4.8
CP-3	1
CP-2	0.57
MW-13	0.54 U

Avg. Benzene concentration =

$$\frac{\frac{0.54}{2} + 4.8 + 1 + 0.57 + \frac{0.54}{2}}{5}$$

= 1.4 ug/l

distance between wells (L) = 460 ft

cis-1,2-dichloroethene

wells	concentration (ug/l)
CP-4	0.55 U
CP-3	21
CP-2	150
MW-13	48
CP-1	3.1
MW-12	0.77

Avg. cis-1,2-DCE concentration

$$= \frac{\frac{0.55}{2} + 21 + 150 + 48 + 3.1 + 0.77}{6}$$

= 37.2 ug/l

distance between wells (L) = 520 ft

Tetrachloroethene (PCE)

wells	concentration (ug/l)
CP-4	0.75 U
CP-3	11
CP-2	8.6
MW-13	0.75 U
CP-1	2.3
MW-12	0.75 U

Avg. PCE concentration

$$= \frac{0.75/2 + 11 + 8.6 + 0.75/2 + 2.3 + 0.75/2}{6}$$

= 3.8 ug/l

distance between wells (L) = 520 ft

Chlorobenzene

wells	concentration (ug/l)
CP-5	0.41 U
SWMU 4/MW-3	48
CP-4	120
CP-3	110
CP-2	16
MW-13	2.5
CP-1	0.41 U

Avg chlorobenzene concentration

$$\frac{0.41/2 + 48 + 120 + 110 + 16 + 2.5 + 0.41/2}{7}$$

= 42.4 ug/l

distance between wells = 740 ft.

2-chlorophenol

wells	concentration (ug/l)
CP-3	0.69 u
CP-4	1.1
SWMU 4/MW-3	0.75 u

AVG 2-chlorophenol concentration

$$= \frac{0.69/2 + 1.1 + 0.75/2}{3}$$

$= 0.6$ ug/l

distance between wells (L) = 290ft

1,4-dichlorobenzene

wells	concentration (ug/l)
MW-13	0.51 u
CP-2	1.8
CP-3	31
CP-4	0.5 u

avg. concentration

$$= \frac{0.51/2 + 1.8 + 31 + 0.5/2}{4}$$

$= 8.3$ ug/l

distance between wells (L) = 390ft

1,2-dichlorobenzene

wells	concentration (ug/l)
MW13	0.98 u
CP-2	1.1
CP-3	15
CP-4	0.96 u

avg. concentration

$$= \frac{0.98/2 + 1.1 + 15 + 0.96/2}{4}$$

$= 4.3$ ug/l

distance between wells (L) = 390ft

1,2,4-trichlorobenzene

wells	concentration (ug/l)
CP-2	0.52 u
CP-3	0.81
CP-4	0.52 u

AVG. concentration

$$= \frac{0.52/2 + 0.81 + 0.52/2}{3}$$

$= 0.44$ ug/l

distance between wells (L) = 300ft

Environmental Resources Management

ERM®

Proj, Phase, Task, Org 0015480.10 Sheet 4 of 5
Project Name Hercules Res. Ctr - Env. Indicators
Subject Calculation of Avg. Parameter Concentrations
By R Devan Date 25 July 2007
Chkd by ______ Date ______

acenaphthene

wells	concentration (ug/l)
CP-3	0.62 u
CP-4	0.63
SWMU4/MW3	0.67 u

AVG. concentration

$$= \frac{0.62/2 + 0.63 + 0.67/2}{3}$$

$= 0.43$ ug/l

distance between wells (L) = 290 ft.

4,4-DDE

wells	concentration (ug/l)
MW13	0.012 u
CP-2	0.022
CP-3	0.052
CP-4	0.082
SWMU 4/MW-3	0.012 u

AVG. CONCENTRATION (C_{gw})

$$= \frac{0.012/2 + 0.022 + 0.052 + 0.082 + 0.012/2}{5}$$

$= 0.034$ ug/l

distance between wells (L) = 460 ft

4,4-DDD

wells	concentration (ug/l)
MW-13	0.011 u
CP-2	0.11
CP-3	5.1
CP-4	0.011 u

AVG. concentration (C_{gw})

$$= \frac{0.011/2 + 0.11 + 5.1 + 0.011/2}{4}$$

$= 1.31$ ug/l

distance between wells (L) = 370 ft

alpha-BHC

wells	concentration (ug/l)
CP-2	0.0084 u
CP-3	0.34
CP-4	0.0084 u

AVG concentration (C_{gw})

$$= \frac{0.0084/2 + 0.34 + 0.0084/2}{3}$$

$= 0.12$ ug/l

distance between wells (L) = 300 ft

Environmental Resources Management

ERM

Proj, Phase, Task, Org 0015480.10 Sheet 5 of 5
Project Name Hercules Res. Ctr - Env. Indicators
Subject Calculation of avg. Parameter Concentrations
By R. Devan Date 25 July 2007
Chkd by ______ Date ______

beta - BHC

wells	concentration (ug/l)
CP-2	0.0056 U
CP-3	0.41
CP-4	0.047
SWMU4/MW-3	0.0057 U

AVG concentration (Cgw)

$$= \frac{0.0056/2 + 0.41 + 0.047 + 0.0057/2}{4}$$

$= 0.12$ ug/l

distance between wells (L) = 370ft

Heptaclor

wells	concentration (ug/l)
CP-3	0.0074 U
CP-4	0.039
SWMU 4/MW-3	0.0076 U

avg. concentration (Cgw)

$$= \frac{0.0074/2 + 0.039 + 0.0076/2}{3}$$

$= 0.02$ ug/l

distance between wells (L) = 290 ft.